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March 25-30, 1979
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WATER REUSE SYMPOSIUM

Theme:
"Water Reuse—From Research to Application"

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The Symposium was devoted to the renovation and reuse of wastewaters from municipal, industrial, and agricultural sources. Unique to the Conference was the use of poster presentations for enhancing author-participant communication. The proceedings demonstrate that significant global interest exists in wastewater reuse, that recycling concepts are being applied to a broad range of functions, that application of water reuse may be highly situation-dependent, and that reuse applications are important solutions for the conservation of water. Symposium objectives include provision of program overviews; presentation of research results and practical experiences; provision of a forum for discussing the problems of reuse implementation, and encouragement of information exchange and technology transfer. Volume 1 focuses on: (1) implementation, programs, and potential of water reuse policy; (2) water supply augmentation; (3) industrial recycling and reuse; (4) planning for reuse; and (5) aquaculture, wetlands, and eco-systems.

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Water reclamation	Proceedings	Ecosystems
Wetlands		

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Any opinions, findings, conclusions
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FORWARD

Wastewater reuse is one of several conceptual approaches to water conservation. It is based upon the realization that not all water users need water of the same quality. The idea of having a given quantity of water serve several different or repetitive functions before reintroduction to the environment is not new, but the rate at which it is increasing is.

Implementation of water reuse depends upon successfully satisfying constraints derived from considerations for environmental and human health effects, economics, process water quality, legal factors, and user acceptability.

The Symposium was the first week-long meeting devoted entirely to the renovation and reuse of wastewaters from municipal, industrial and agricultural sources. Unique to the Conference was the use of poster presentations for enhancing author-participant communication. Where quality photos were available, they are included at the end of several written manuscripts presented as posters.

These three volumes of Proceedings demonstrate that significant global interest exists in wastewater reuse; that recycling concepts are being applied to a broad range of functions; that application of water reuse may be highly situation-dependent; and that reuse applications are important solutions to conservation of water.

The objectives of the Symposium were to:

1. Provide program overviews
2. Present research results and practical experiences
3. Provide a forum for discussing the problems of reuse implementation
4. Encourage information exchange and the transfer of technology

These objectives were addressed and met by the 155 Symposium papers.

No attempt has been made to edit, reformat, or alter the material provided except for printing production requirements or where obvious errors or discrepancies have been detected. Any statements or views here presented are totally those of the speakers and are neither condoned nor rejected by the Symposium co-sponsors.

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MILLER, Roy D.	2	1269
MILLIKEN, J. Gordon	2	1051
MILLS, Robert L.	3	1693
MOORE, Rebecca S.	3	2274
MORGAN, James T.	1	167
MORRIS, Phillip J.	3	2248
MOZUMDER, Sashi K.	2	1139
MURPHY, Daniel F.	2	1086
NAITO, Sachiho	2	1021
NEAL, M. W.	3	2209
NELLOR, Margaret H.	3	2146
NIBLEY, David	3	1779
NISHIOKA, Kenji	3	1779
NUTE, J. Warren	1	727
ODENDAAL, Peter E.	2	886
OLIVA, James A.	1	199
OLSON, Betty H.	2	1219
O'NEILL, Patricia E.	3	1917
OSANTOWSKI, Richard A.	1	283
PAHREN, Herbert R.	3	2170
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PARKER, Clinton E.	3	1737
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PERRINE, Richard L.	2	1099
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PORTER, Janet E.	3	1895
POUSCHINE, Ivan, Jr.	1	295
POWELL, J. David, Jr.	3	1843
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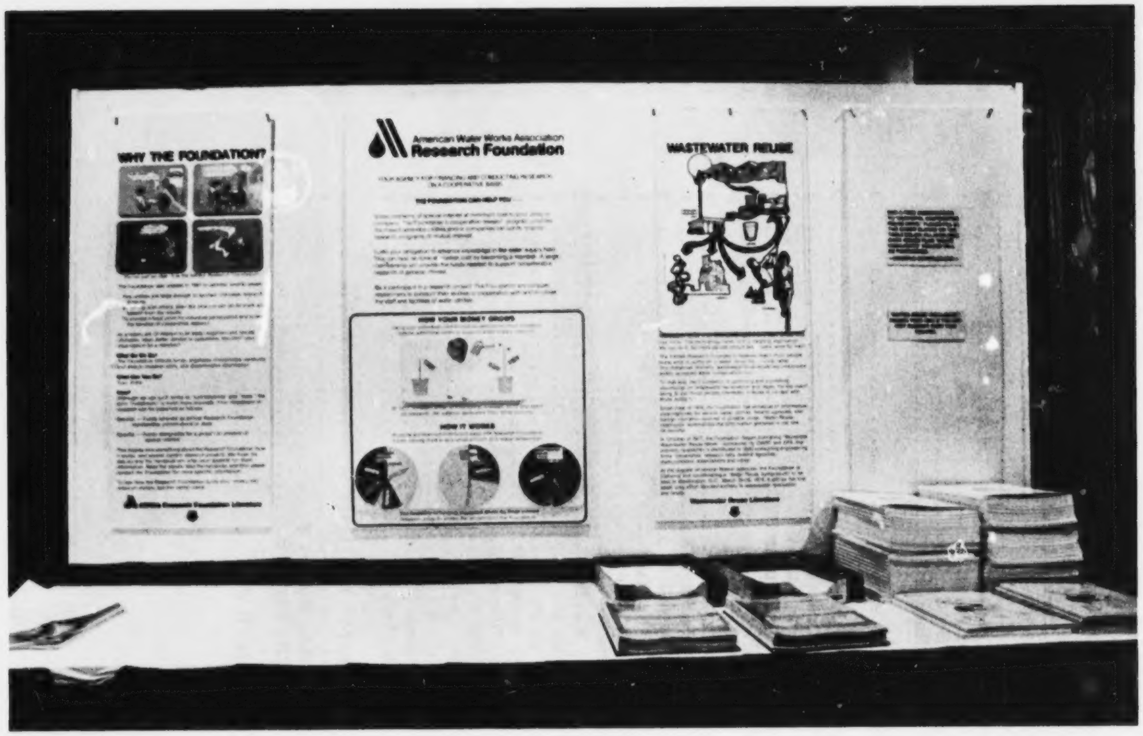

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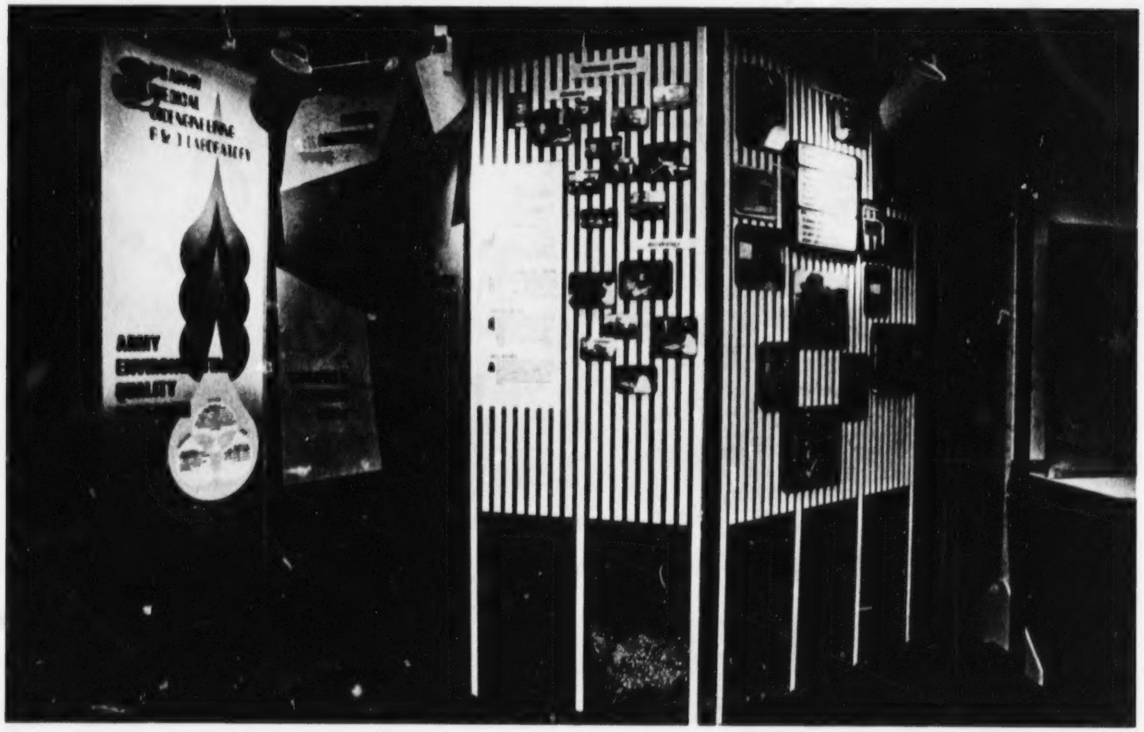

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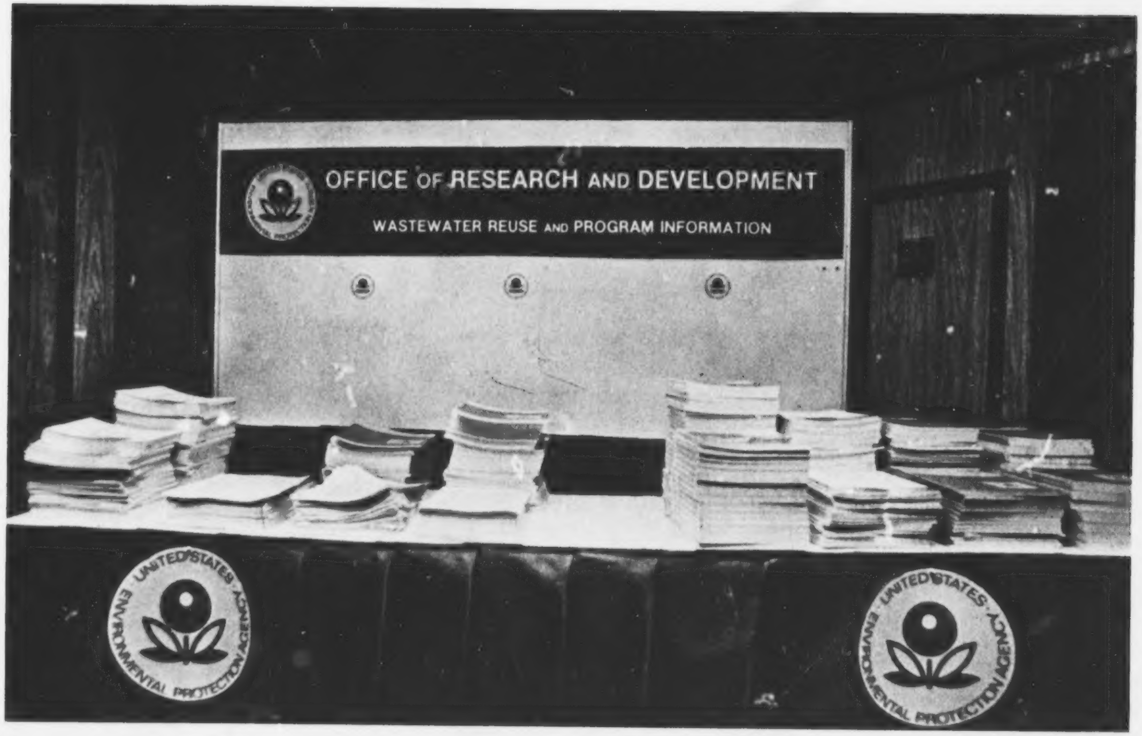
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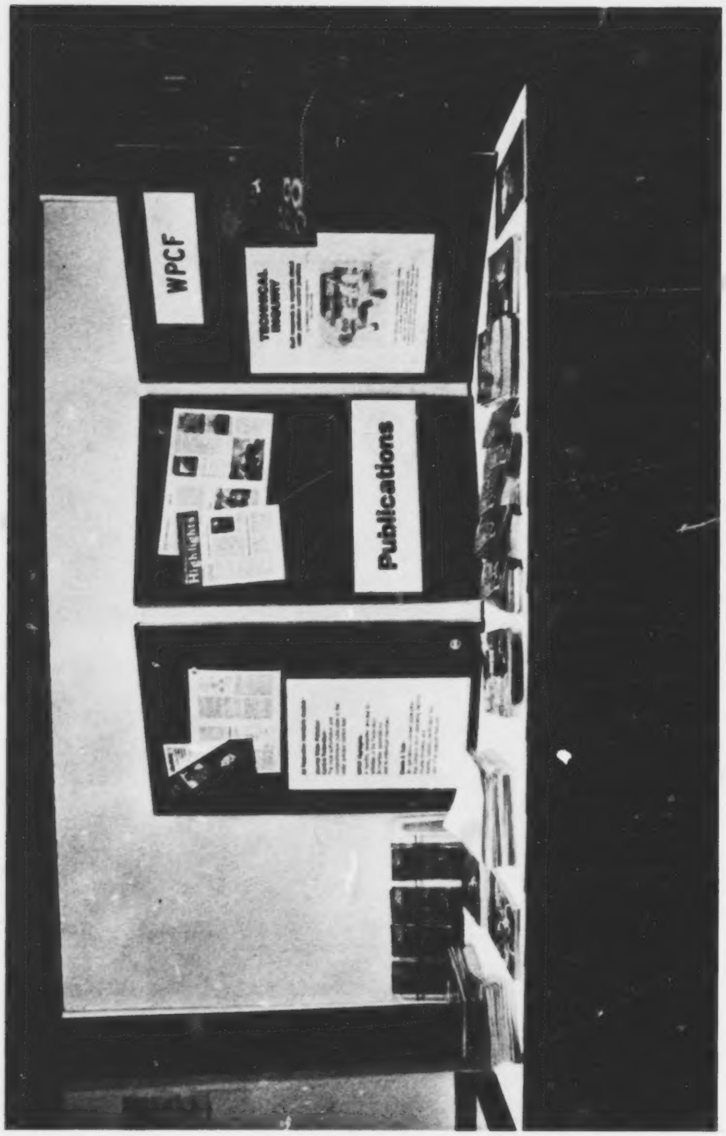

Water Pollution Control Federation

WATER REUSE
SYMPOSIUM

WATER REUSE POLICY, IMPLEMENTATION, PROGRAMS AND POTENTIAL

THEME ADDRESS
"WATER REUSE - FROM RESEARCH TO APPLICATIONS"

LTC Le Roy H. Reuter
Chief, Environmental Protection Research Division
US Army Medical Bioengineering R&D Laboratory
Ft. Detrick, Frederick, MD 21701

It is a very flattering but humbling experience to stand before this audience with the charge of presenting the theme address at this symposium. Every one of you knows more than I about certain aspects of water reuse. What then can you learn from this talk that you don't already know? Nothing! The goal of this presentation is to help you discover what you already know. The goal of this symposium is similar - to provide a forum for conceptualization, followed by introspection.

The theme of this symposium is "Water Reuse - From Research to Application." The words in the symposium title, "From Research to Application," are as all encompassing as another great from-to title: "From Here to Eternity." It's tempting to put emphasis on just the words research and application, and forget all must occur, all that is essential between research and application for water reuse to be successful and optimally applied. Like a race - the start, which is analogous to the research, is exciting. There is jockeying for position, anticipation, getting ready, the initial burst of energy. The finish line, the application, is where the winner is determined. It is the payoff. But the running of the race, that's the work, that's where you make up ground, or fall behind, where you win or lose. Between research and application of water reuse lie the development and transfer of technology, the know-how for design and manufacturing; overcoming institutional barriers, and integrating political, social, economic, environmental, and human health factors with the engineering aspects.

There is no final finish line to this water reuse race - no real end - in the symposium logo (Fig. 1) the two point to tail arrows were chosen to represent reuse or recycle, but they also can imply the feed forward process of information from research towards application and the equally important feedback process of information from application to earlier stages. The arrows can be thought of as depicting motion - movement around an axis. This cycle is entered at different points depending on the problem and what is known about it. The movement also depicts the dynamic nature of this complex area.

The logo can also be imagined to be three dimensional - a sphere or globe. The globe represents the earth and the supply and demands for water. The agricultural, industrial, and municipal demand cohorts are symbolically represented in the logo. The first letters of these demands spell out aim. It is important that we select our targets wisely and aim carefully.

Are things out of kilter with water reuse? Are the arrows matching up - in a timely, efficient, effective way? I believe the water reuse sphere is becoming out of kilter - there is growing inbalance - or a threat of it - too much emphasis on single discipline studies. Put another way, there is too little emphasis on multidisciplinary,

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comprehensive studies. Government agencies must share the blame for this: really take most of the blame for it - government funding has spearheaded water reuse research and strongly influenced its total direction. A finger must be pointed at myself and my bureaucratic colleagues. Researchers are obliged to work in areas for which they can get government support and municipalities are tempted to construct what can be federally supported.

The time is right for this symposium. A meeting that presents the full spectrum of water reuse - from research to application. Water reuse is the main event.

Fourteen sessions with 81 papers, 76 poster presentations, and two plant tours to finish off the week. Gathered are the champions of reuse and for balance, hopefully, some challengers. Industrial, agricultural, and municipal reuse opportunities are all included in the program. Planning, policy, research, and status reports on operating systems are all covered on a US and on an international level. You will hear reports from the private sector and from all levels of government. The sponsorship of this symposium by six activities is itself noteworthy. Six prima donnas don't usually dance together long enough to do anything. Maybe we're learning.

The complex, dynamic water reuse opportunities cry out for a multidisciplinary approach - a merging, an integration. Renaissance men are needed.

Many aspects of water reuse are approaching phases that require a merging of science and engineering with social, political, and economic implications. This requires the bringing together of groups that historically have lacked cooperation or even close association.

Many of us aren't particularly gifted at these tasks. The terrain is unfamiliar to many, quicksand to some, and at a minimum, a slower uphill climb. It is time to take risks. Change involves risk taking. But let us rush slowly, taking calculated risks where water reuse affords the best alternative for meeting water demands.

Water reuse must overcome some obstacles - first there is public apathy. Water reuse is viewed as a "future" consideration; it is not a "now" issue. The public believes there is certainly enough time for technology to solve this problem of water reuse if it materializes. The recent and not so recent droughts are already mostly forgotten by the public. What can we, those concerned with water reuse, learn from the energy crisis? The government action and public reaction to the energy crisis. With this comparison, it is surprising the progress water reuse has made and the support it enjoys. The progress and support stand as tributes to those dedicated individuals and organizations who have plugged away.

Second, reuse is considered a local or regional issue. Water reuse is not a high priority, world-wide or national issue. It is difficult to get federal government momentum behind regional issues.

Next, approaches that reduce demand or limit supply are unpopular. They are almost un-American. Growth is considered the true measure of success and goodness. Historically, the favored approach to meeting increases in water demand has been to expand supply. The alternatives or modifying demand by pricing, conservation, restrictions on growth, and engineering and technology changes to systems are only recently gaining support.

The twin obstacles of ineffective education and communication need to be overcome. The public is not well informed on the reuse capabilities. They do not know how advanced water reuse technology is. This situation explains in part the public's apathy. If this symposium has a fault, it is that we are talking mostly amongst ourselves again. Telling each other what we want to hear, what we already know, or worse, what we already know isn't true?

The "man on the street's" first impression of water reuse is probably the transference of sewage into drinking water. Ingestion of water, man's most intimate water usage, is the first throught. Water reuse suffers from a space age image - conversion of urine into drinking water.

The name, reused water, isn't too good either. What kind of person buys reused water? Maybe we should take an example from the skillful name changing that has been applied to welfare - from dole to relief to welfare to now, negative income tax. When a name has a stigma, change it. So what about changing reused water to - antique water, vintage water, experienced water, or previously owned water.

It's frustrating to finish a project and find that the user doesn't want the product. He isn't ready forwhat you've just finished. You look around and try to figure out what happened. A couple of years ago, you thought people were demanding an answer to this question. This is a problem in communications. More time needs to be spent searching for the perfect questions - not for answers to poor questions. Now the logical follow-on to a statement like this would be to produce a list of perfect questions on water reuse.

Sorry, I don't have them. But I'm going to be listening this week because I think this conference can help me and you discover some of these questions. And then, it's back to the race.

Figure 1

WATER REUSE IN THE DEPARTMENT OF DEFENSE

George Marienthal
Deputy Assistant Secretary of Defense
(Energy, Environment and Safety)

Thank you, Mr. Lang. It is a real pleasure for me to be here today representing the Department of Defense at the Water Reuse Symposium. I am honored to be speaking with so many experts in the water reuse field.

I feel like, however, the fellow who survived the great Johnstown flood of 1936. Wherever he would go, whomever he would meet, he told of the great flood of '36. Ad Nauseam! When he died, St. Peter met him at the gates and, as was the custom, offered to grant one wish. His wish, of course, was to tell a great audience about the great Johnstown flood. So St. Peter assembled a huge crowd and summoned him to the podium. Proudly, enthusiastically, excitedly, anxiously he walked to the podium, followed promptly by another man, which was perplexing. Silence befell the crowd and St. Peter started the introductions. "Today, speaking to us on floods is a representative from Johnstown and Noah."

Though I'm not from Johnstown, the similarity is striking.

The Department of Defense is fully committed to conserving our Nation's resources. We view wastewater recycle and reuse as a means to further this basic commitment. Our interests in the conservation of clean usable water, an evermore critically short natural resource, is evidenced by our co-sponsorship of this Symposium through the U.S. Army Medical Research and Development Command at Fort Detrick, Maryland. We are interested and involved in the conservation of all our resources, of which water is just one. The name of the game for almost every area of our business is resource conservation. Our energy conservation program, for example, has resulted in an energy savings of over 30 percent since 1973. Our installation energy consumption alone is currently 15 percent less than in 1973. As the Nation's largest single energy user (nearly 270 million barrels of oil equivalent at a cost of four billion dollars), these savings are significant. We hope in the future to realize similar successes in water conservation.

Defense's water supply problems are, in general, no different from any of yours: enough good water at the right place. With increased treatment costs, increased supply costs, and increased disposal costs, waste effluents are becoming too valuable to throw away. Used water is becoming, in fact, a practical source of good water. We see water reuse as just plain wise management. If fully developed, water reuse should be cost effective, should increase our operational capability, and should ease all of our installation demands for fresh water.

This morning, I will give you a brief overview of the Department of Defense's interests and activities in water recycle and reuse. First, I will identify our major potential wastewater reuse applications, which are many. Then, I will examine some of our unique water problems. Finally, I will outline our current research and development efforts. I will defer any detailed discussions of specific projects to my Army, Navy, and Air Force colleagues, the real "Noahs" who work our water reuse problems.

There are literally hundreds of potential applications within the Department of Defense for water recycle and reuse. Our permanent installations are like small to medium sized cities. Some are highly industrialized, while others are more like residential communities. We have fixed and mobile unit requirements for combat operations, both for land based operations and aboard our ships. We see water reuse as a means to increase our water management options, to decrease our advanced base resupply problems, to increase our base siting options, and to insure base self-sufficiency.

Some military applications for water recycle and reuse that we are investigating include, vehicle and aircraft wash facilities, shower facilities, and laundry facilities. These water uses are unique for the military because of their size, their mobility requirements, and the control which we can exercise over the process parameters. Our shower, laundry, and vehicle washing facilities are large. They are set up as individual unit processes. Those three account for over 25 percent of the water demand for a field army unit. A fighting force of 30,000 people, for example, would use about one half million gallons of water per day, and, of this, 130,000 gallons would be used for showers, laundries, and vehicle washing. Reuse of this water at an efficiency of 80 percent would eliminate the need for over seven 5,000-gallon trailer trucks and 21 men operating full time to deliver water to the field.

Other potential reuse applications at our permanent installations include plating plant process water, air conditioning and rectifier cooling water, paint water walls, and, of course, irrigation water. Practices, such as the recycle of fume hood scrubber water in our plating plants, the use of reclaimed water for air conditioning, and cooling of rectifiers, and paint water walls, have been shown to significantly reduce raw water consumption.

Congress has added emphasis to our consideration of wastewater recycle and reuse through the 1977 amendments to the Federal Water Pollution Control Act. All federal agencies must, after September 30, 1979, use innovative treatment processes and techniques for water pollution abatement facilities. This includes, but is not limited to, methods utilizing recycle, reuse, and land treatment. Innovative treatment must be used when its life cycle cost is no more than 15 percent greater than the most cost effective alternative.

That wraps up what I wanted to tell you about overall applications with Defense. Let me now briefly describe our research and development opportunities. Within the Department of Defense, our water reuse research and development efforts are directed primarily towards solutions to unique military problems. We are involved, however, in joint research with other agencies where our expertise and facilities can be used to mutual benefit. The broad goals of our water reuse research programs are (1) to develop water quality criteria to define the reuse potential for candidate applications, (2) to improve process engineering to achieve these criteria and reduce water demand, (3) to improve analytical methodology for real-time monitoring and control of emissions, and finally, (4) to construct models which can be used to evaluate water reuse and conservation strategies for specific installation requirements.

Most of our research effort in water quality criteria development has been for nonpotable reuse, particularly for those applications which I mentioned earlier--shower, laundry, and vehicle wash waters. In these situations, treatment of wastewater for nonpotable reuse cannot only greatly reduce the demand for raw water as mentioned previously, but also result in a savings of manpower, acquisition costs, and energy requirements. This is particularly true in cases where water must be transported over long distances or where the source would require extensive treatment.

Our primary concern in potable water criteria has been for short term, emergency field use. Remote military installations in water-short areas are not using expensive, energy-intensive processes to purify water for all uses. In such cases, potable reuse is the most cost effective military option, and potable water quality criteria will be developed for such reuse.

Within our water reuse research program, we devote considerable attention to the area of process engineering. The center for our efforts in this area is at Fort Detrick, Maryland. The Fort Detrick pilot plant is equipped to study the treatment of domestic or industrial wastewaters. They examine methods for both biological and physical/chemical treatment. The processes available range from simple sedimentation to ultraviolet and ultrasonic ozonation, with a broad range of processes in between. They monitor and analyze these processes using a minicomputer system which collects data and, through a feedback system, controls the process. This facility is an invaluable asset to our wastewater research efforts. Bill Cooper, a research chemist from the Fort Detrick Environmental Protection Research Division, will tell you more about the pilot plant on Tuesday morning. In addition, you will have an opportunity to tour this facility on Friday morning.

As a part of our process engineering efforts, we have also looked to reduce or to eliminate "once through" water use processes. At our air logistics centers, implementation of process changes such as counter current rinsing, recycle of fume hood scrubber water, and collection and reuse of dilute sump water for housekeeping rinse waters has resulted in a significant reduction in raw water demand. Also at the U.S. Air Force Academy, we have eliminated once through water use through utilization of the wastewater effluents for irrigation of the Academy grounds. Through the utilization of successive water use, we have achieved double savings: reduction in our raw water demand and reduction in the amount of wastewater that must be treated.

At the Air Logistics Center at McClellan Air Force Base, Sacramento, California, we had considerable incentive to investigate the reuse of wastewater. The state wanted us to join, totally, their regional treatment plant. Through an economic analysis of the alternatives, we determined that the most cost effective alternative was partial connection with reuse and land application. A significant cost avoidance was realized and, like any large corporation, we opted for "cheaper is better." That is what we are always seeking to achieve, dollar savings.

In the third Research and Development area, development of analytical methods, we are working on techniques to insure that the water reuse criteria are being met. We are investigating laboratory chemical analyses to characterize wastewaters before and after treatment. These techniques will also be used to insure that the various processes being tested produce waters of the desired quality. The military departments sponsor, with the Environmental Protection Agency, a program to develop low cost, continuous monitoring of total organic carbon and chemical oxygen demand. These parameters will be used to monitor process efficiency when monitoring, for example, the effluent of reverse osmosis or ozonation unit processes.

Analytical methods are also required to evaluate the particular wastewater reuse potential at our individual installations. The Air Force saw this need and developed computer models to assist in water and wastewater management. One model, called the Cascade Water Reuse Model, provides a systematic methodology to organize the basic information required to evaluate the wastewater reuse potential and to determine the optimal reuse system. The model has been used successfully at Peterson Air Force Base, Colorado, to design a reuse system for landscape irrigation. It was also used at McClellan Air Force Base, California, to design the combined municipal, industrial wastewater reuse system which I previously mentioned. Both the Army and the Navy have joined the Air Force in sponsoring research to extend the use of this model to their facilities.

In conclusion, we have, throughout the Department of Defense, developed integrated water reuse programs which are providing solutions to our water problems. We are fully committed to conduct wastewater research for our unique military applications. We do participate in joint research, however, when our areas of expertise may add to the solution of common problems. All and all, we view wastewater recycle and reuse as a viable water alternative in wastewater treatment, water source development, and our overall resource conservation program.

Thank you for this opportunity to speak to you today. Now for Noah.

WASTEWATER REUSE PROGRAM AT THE US ARMY MEDICAL BIOENGINEERING RESEARCH AND DEVELOPMENT LABORATORY

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James C. Eaton
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Barry W. Peterman
Sanitary Engineer

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Introduction

The US Army Medical Bioengineering Research and Development Laboratory as an operating arm of the US Army Surgeon General chartered by the US Army Medical Research and Development Command is responsible for the Surgeon General's environmental quality research program. Among the many research areas which are included in this health effects oriented program are those for water supply and wastewater treatment research.

The purpose of this paper is to outline the development of this laboratory's efforts in wastewater reuse. The historical background provided will put several papers to be presented during this symposium into perspective. The program as it exists today and future programs will also be discussed.

Historical Development

The Medical Research and Development Command was, in the early 1960's tasked with the development of a modular, highly mobile, field hospital system (1). Included in the conceptual design of this system was the requirement to reuse non-sanitary wastewater. The intent of this design goal was to increase the mobility of the hospital while reducing the logistical burden. The water/wastewater treatment system to be associated with the hospital was to be used for reuse where water supplies, raw or treated, were inadequate, or for wastewater treatment for discharge with simultaneous potable water production when raw water supplies were available. The major constraints which the system would have to meet were in power, weight and size.

The first generation of these water processing elements failed field tests in 1971 for a variety of reasons. Following this failure efforts were initiated to develop a second generation system using newly acquired technology.

Bench and breadboard experimentation, which began in 1973, was used to determine the unit processes necessary to meet design criteria (2). The mobility factor and the need to rapidly assemble or disassemble the system favored the use of physical/chemical processes. Bench-scale study of the processes selected as a result of preliminary treatability studies addressed the use of reverse osmosis for removal of organic compounds (3) and the use of UV catalyzed ozonation for oxidation of low molecular weight organics (4-7). Development of the system was continued in 1976 with the fabrication of a pilot plant (8-13). The pilot plant was installed at Fort Detrick for further process evaluation and development of the computer control systems.

The desire for a highly reliable system was central to the adoption of a microprocessor control system (14). The use of this type of control would assume that sensors would be available to measure designated control parameters. Since some of these measurement devices were not available, projects were initiated in 1974 to develop on-line instrumentation for chemical (15-20) as well as biological or toxicity (21-25) parameters. Among these efforts were projects to provide rapid measurement of organic chemical concentrations using electrochemical techniques. Analytical methods were also sought to develop a toxicity monitor using potential off-line and on-line techniques.

Although the process and control development efforts dominated the program in the early years, a need was recognized for research to develop analytical methods and criteria. Comprehensive planning was initiated in 1975 to describe a program that would lead to the recommendations of non-potable reuse criteria, for field Army use, by 1980. This planning included the development of a management plan to help guide what was perceived to be an intricate program. Although other parts of the reuse effort have taken numerous turns during the last several years, the criteria development effort has retained its original goal. The management plan (26), finalized in 1978, has prescribed a course of action that will permit recommendation of reuse criteria for field Army use as early as mid-1979.

Program Structure

The research program has been structured to provide for simultaneous investigations of health effects criteria, analytical methods and process engineering. Although the first two of these categories are essentially the same as in the original program, the third has changed significantly. From the dominating role, in the early program where process development was stressed, process engineering is now directed at studying application of various processes to potential reuse situations. This effort is conducted in conjunction with the criteria development program.

Process Engineering

Current process engineering efforts are an outgrowth of a project directed at hospital wastewater reuse process development. In 1973, a project was initiated to determine those processes which would provide a level of treatment of non-sanitary wastewaters that would render them safe for reuse (2). Target values for this effort were the 1962 USPHS drinking water standards supplemented with organic chemical limits represented by a TOC of 5 and a COD of 10. Although a number of processes were assessed, the system which was determined to most effectively meet the design targets and the stringent operational characteristics, consisted of hydraulic equalization, tubular ultrafiltration, hollow fiber reverse osmosis, UV catalyzed ozonation and hypochlorination.

Engineering evaluation of the processes selected for the pilot study continued on various scales to quantify contaminant removal or optimize operation. The focal point of these studies was the ozone oxidation process. Included were the evaluation of the effects of ultrasound (27,28), the use of ozone and high pressure (29) and the impact of varying UV intensity (30,31). A pre-pilot scale ozone contactor system was developed (32) to provide design data for the pilot system.

While bench studies on the ozone process continued, a pilot plant for testing the treatment schemes and other processes was assembled. The first process to be installed in the pilot plant was a self-contained tubular reverse osmosis system (33). This was followed by a three pallet 4500 gpd pilot system that included the treatment process scheme previously mentioned (8-13). This system was linked to a distributed mini-computer system that would be used to perform data collection functions and exercise control options through a procedural model. Once installed, work was initiated to mathematically describe several of the unit processes (34). These models would be used to develop the fault detection, isolation concepts for the control system.

Although the project to develop the hospital reuse capability was terminated in early 1978, the processes which were a part of this project were used as the basis for the new wastewater pilot plant facility. The operational emphasis for this facility is on the assessment of unit processes for their application to Army reuse requirements. To fulfill this need, flexibility has been incorporated into all unit processes.

In addition to the processes acquired as a result of the hospital reuse effort, the laboratory has recently completed the relocation of its advanced wastewater treatment pilot plant. This plant, which is tied to a domestic sewage source, has actually been on-line since 1974 and was designed to provide design data for upgrading Army wastewater treatment plants. Sedimentation, activated sludge, trickling filters, rotating biological contactors and flocculation are among the processes added to the pilot plant system.

Other processes which have been evaluated and are available for study include ion-exchange, multi-media and diatomaceous earth filtration, carbon adsorption and vapor compression distillation. The most recent process to be added to the pilot plant is tubular microfiltration (35) which will be included as a process for treatability studies of shower and laundry wastewaters.

Criteria Development

The primary emphasis of the present program is on the development of health-related reuse water quality criteria; however, it is obvious that criteria development must be integrated with process engineering and analytical methods development if practicable reuse water quality criteria are to be developed. The ultimate goal is to provide a reasonable, scientifically validated guarantee against adverse health effects from military wastewater recycle or reuse. In order to achieve this goal, a data base must be assembled to include characterization of the wastewaters and treated waters and toxicological evaluation of possible adverse health effects of the identified constituents in the specific applications and situations in which military reuse is being considered. From the assessment of this data base, health effects criteria will be developed for each of the reuse situations. Final water quality criteria will consist of specifications of the treatment processes and operating conditions that will provide water that satisfies the health effects criteria, plus analytical methodology for monitoring and control, to give assurance that the treatment system is operating within the prescribed bounds.

The criteria development project was initiated with an overall assessment of potential contaminants likely to be found in hospital wastewaters (36). Several compounds were identified for which information gaps existed and additional data was necessary (37).

It was determined that shower and laundry represented a large portion of the wastewater generated in a field hospital and a combined effort was undertaken to treat and test, shower and laundry wastewaters (38-40). These data are now under evaluation (41) and are the subject of a presentation during this symposium.

Derivation of health effects for exposure to a compound or group of compounds depends upon quantification of the answers to three questions:

1. What are the conditions of exposure? (Who is exposed, by what route, for how long?)

2. What is the level of exposure (the dose)?

3. What is the relationship between dose and possible adverse effects?

The population to be exposed to military applications of recycle reuse will vary from a strictly controlled group of young healthy adults, such as in the military in the field, to the entire population of a fixed facility, which may run the gamut from infants to the aged and can include the sick and the pregnant, occupants of hospitals, prisoners and civilian workers and dependents. For each reuse situation, the populations can be characterized. Routes of exposure are also dependent upon the reuse application. Possible routes are: ingestion, aspiration or inhalation, systemic exposure via skin absorption, and direct exposure of skin and eyes.

The extent of exposure or "dose" also depends upon the reuse application and situations as well as upon the concentrations of the identified constituents suspected or known to have adverse effects. Duration of exposure, as defined by the conditions and situations in which wastewater recycle or reuse is to be employed, will range from one-time emergency exposure (several hours to a maximum of 1 week) through an intermediate exposure such as might be applicable to more routine field military operations (on the order of 1 year) to exposures that may last a number of years, and must therefore be considered as "lifetime" exposures.

The reuse application also defines the level of human exposure. We have identified four levels: direct, total body contact such as in showers; indirect contact, such as with residues from laundries; incidental, such as from vehicle washracks and other industrial applications; and potable. Irrigation involves incidental, industrial-type contact, plus ingestion of residues.

Definition of the dose-effect relationship is the least precisely quantifiable of the tasks in deriving health effects criteria. There is no convenient tabulation of the human health effects of various compounds at various doses. Nevertheless, these data are the best available measurements of the effects of materials upon human health, and are routinely used by toxicologists in projections of the relative safety of various materials to humans.

In order to define the conditions of exposure that may be encountered in military applications of recycle or reuse, we have constructed a three-dimensional matrix as shown in Figure 1. The level of human contact is one axis, the route of exposure forms another axis, and the third axis represents the duration of exposure to the military reuse application. Conditions of exposure are thus defined for any box in the matrix. It is conceivable that specific water quality criteria could be developed for each such box. Some of the boxes in the matrix, however, are not applicable or practicable for the military, and it is likely that categories may be broadened in many cases, since it may be cost-effective to provide water meeting the highest demand for quality among several conditions of reuse rather than attempt to provide many sources of water of varying quality. In all cases of recycle, where wastewater is treated and reused in the same use as the one in which it originated, use-specific water quality criteria must be provided.

The definition of exposure conditions provides an empty shell which can be filled with water quality criteria by determining the chemical and microbiological character of the wastewaters and treated waters and by developing the dose-effects relationship. Those two tasks can be initiated in parallel. At the same time, or even before the military opportunities for reuse are defined and the waters characterized, a protocol for evaluating the health effects data base will be developed. By proceeding in this manner, it will be possible to present, to the panel of experts who will recommend water quality criteria, a set of criteria by which they may judge the adequacy and applicability of the health effects data base to the task before them. This protocol will be specific enough to spell out what data will be necessary and sufficient for deriving health effects criteria for each of the conditions of recycle or reuse defined in the matrix of Figure 1 and to indicate a methodology for deriving safety factors based upon the quality of the available health effects information. It is intended that this protocol for defining the data base requirements and evaluating the available data will be submitted for review to the National Academy of Sciences, through the Subcommittee on Water Reuse of the Committee on Military Environmental Research.

The approved protocol will be given to a panel of experts convened for the purpose of preparing the health effects criteria document. This is the procedure recommended in the management plan developed through research sponsored by our laboratory, the Navy's Civil Engineering Laboratory at Port Hueneme, CA and the US Army Mobility Equipment R&D Command (26). In addition to the data base requirement protocol, the panel will be given a complete description of each proposed military recycle/reuse application, to include the demographics of the population exposed, the conditions of exposure (site, extent and duration); characterization of the wastewaters and dilution waters for make-up, identity and amount of contaminants to be added during each reuse cycle and a description of treatment processes likely to be employed and their removal efficiencies for the identified contaminants or contaminant groups.

As a first finding, the panel will determine in each proposed military reuse application whether there is a significant risk that such reuse will result in an added burden of adverse health effects. If no such risk is found, the panel will proceed directly to preparing a criteria document for that wastewater recycle/reuse application or group of applications. Where there is found to be a significant risk of adverse health effects, the determinations of acceptable risk must be made by the military on the basis of benefits to the military mission vs. costs, the risks incurred by providing water by other means, and the cost of doing without. This determination may be made by a group of military medical and sanitary engineering personnel drawing upon the expertise of the panel convened for preparing the criteria document and upon their own experience in surveillance of fixed and field military water supplies.

The results of the health effects evaluation and of any risk assessments that may be necessary will be brought together to form the basis of a criteria document prepared by the panel of experts as recommended in the management plan. This criteria document will state for each recycle/reuse application the target levels of maximum concentration of all compounds or groups of compounds identified as having a significant potential adverse health effect in the ranges considered. These levels will be based upon human health effects without regard to other considerations. All criteria documents will be presented to the NAS reuse subcommittee for review and to the Surgeons General of the three services for approval.

Final water quality criteria will be prescribed, based upon the health effects criteria document and upon the water treatment technology that is practicable for the situation in which the recycle/reuse capability is proposed. Additional considerations will be the availability of monitoring and control facilities and the availability and skill levels of personnel to operate the treatment systems. These criteria will serve as guidelines for the developer of the treatment system giving him the maximum contamination levels or removal efficiencies needed to provide a guarantee against adverse health effects from the proposed application of recycle/reuse. In addition to or in lieu of physical/chemical criteria, treatment criteria may be provided to indicate the treatment techniques and operational bounds necessary to achieve the physical/chemical criteria. Because of the integrated program at USAMBRDL, it will be possible to present to the equipment developer not only the health effects criteria but an appraisal of the ability to meet these criteria with fieldable treatment processes, and an evaluation of the state-of-the-art of monitoring and control technology to provide the necessary quality assurance.

Analytical Methods

In considering water for reuse an important consideration is the use of analytical methods, chemical and biological, for water quality assurance. An additional utilization of on-line instrumentation would be in monitoring and control of unit processes. Recognizing these facts a project was initiated for analytical methodology development in 1973 which evolved into consideration of on-line and off-line techniques for chemical and biological analyzers.

The initial thrust was to develop rapid quantitative methods for analyzing volatile organics which might result from treatment using reverse osmosis and/or ozonation. A static headspace procedure (42) was developed which could analyze compounds with a boiling point up to approximately 150°C. This procedure required 2 ml of aqueous sample and could be accomplished in 15 minutes.

The limit of detection for this procedure, depending upon the organic compound, ranged from 0.01 mg/L for acetone to 1 mg/L for methanol. In order to extend the detection limit it was suggested that a distillation precede the headspace analysis. This hypothesis was tested and the new procedure was found to give a lower limit of detection (43). The drawback of this procedure then becomes that of added time. Both of these procedures have proved to be good analytical tools, and the static headspace procedure is used routinely in our laboratory.

In 1975 it was recognized that in order to insure a water of adequate quality for reuse, on-line analyzers needed to be employed. The surrogate procedures of total organic carbon (TOC) and chemical oxygen demand (COD) were targeted as potential parameters of interest (18-20). Since no suitable equipment was commercially available for these procedures, an effort was initiated to develop a low cost, on-line, continuous, accurate and inexpensive monitor. The initial phase was a feasibility study for a new procedure called the electrochemical organic content (EOC) analyzer and a paper study for electrochemical TOC and COD analyzers (15). The results of this proved the feasibility of the EOC analyzer and suggested that TOC and COD could be adapted to on-line instrumentation utilizing electrochemistry. The EOC analyzer employs a differential capacitance reading which is related to total organic load (44). This has been developed to the breadboard phase and is the subject of a paper in this symposium.

The electrochemical TOC and COD concept is to use *in-situ* generation of persulfate and a recycle loop to give a continuous on-line analysis (17,45). The consumption of persulfate is proportional to the chemical oxygen demand of the samples, and the amount of CO_2 produced is proportional to the total organic carbon (after inorganic CO_2 is stripped). This has developed and is currently in the advanced breadboard design and testing phase. It is anticipated that preprototype units will be available for purchase and testing in 1980.

The development of biological methods of analysis involves less well-explored territory than that of chemical instrumental techniques. The concept is to use a biological system to give relatively fast response related to cellular toxicity, an on-line biological toxicity detector. We have supported one effort in this area, where cells were cultured in artificial capillaries, hollow fibers of various semipermeable polymeric materials such as cellulose acetate, polysulfones and acrylic copolymers (24,25). Small bundles of these capillaries were perfused with culture medium containing various concentrations of known toxins, and oxygen consumption was measured. Reduction in oxygen utilization within 30-90 minutes was of the same order of magnitude as inhibition of cell growth in 72 hours by the same concentrations of the same toxins, thus indicating the feasibility of using such a technique to measure sublethal toxicity of waters.

Other studies that we have supported are off-line biological methods such as the tissue culture work which correlated cell growth to water toxicity (22, 23). This work has been completed, and a final report is in preparation. An off-line technique is currently being developed under our sponsorship at the Armed Forces Institute of Pathology (21). This system utilizes a minicomputer to drive a light microscope, to convert and store cytologic images, and to analyze the collected data and correlate cytotoxic reactions with length and intensity of exposure to pollutants. The feasibility of using such a system for non-specific detection of toxic impurities in water and the sensitivity of the detection system are now being determined.

The wastewater reuse program is divided into three research areas, which provide a multidisciplined approach to multifaceted problems. This integrated program represents our approach to solving the problems ahead in wastewater reuse. It is this integrated programming that is needed to achieve water reuse "from research to application."

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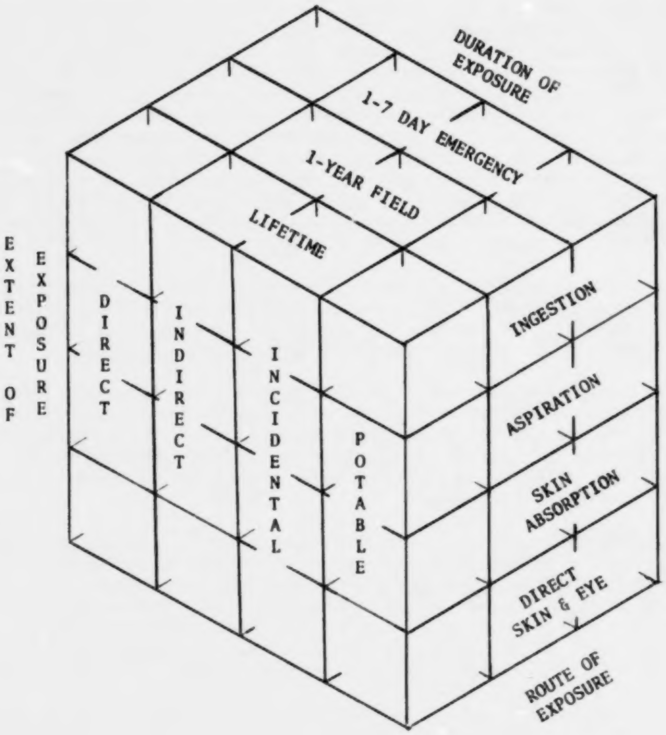
FIGURE 1. MATRIX OF HEALTH EFFECTS DATA BASE REQUIREMENTS FOR MILITARY REUSE WATER QUALITY CRITERIA



KEYNOTE ADDRESS: THE PRESIDENT'S NATIONAL WATER POLICY IN RELATION TO WATER REUSE

Guy R. Martin
Assistant Secretary
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I am delighted to be here this morning to join the representatives of the six sponsoring organizations in welcoming you to Washington.

I want to talk to you this morning about national water policy--what it is and how it is being carried out. This is important business for all of us. It is the first comprehensive water policy specifically drawn up by a President of the United States in many decades. It follows years of study and many reports by Commissions, but until now, no action by a President on such a policy.

Ever since June 6, 1978, when the President first introduced his national water resources policy to the nation, the discussion about water problems, water needs, water uses and water policy has grown. I have spoken at dozens of meetings and conferences, to big groups like this one and to small meetings in little towns all across the United States. Almost without realizing what was happening, people have started talking about the water problems and the water needs of the nation. They are no longer questioning the need for a national policy --they are debating about what our national water policy should be. The debate has clearly moved from arguments over the procedures for developing a policy to a substantive discussion of the policy the President has stated. There is no going back.

I am proud to be a part of the Administration which triggered this debate. I believe President Carter is the first President in many years to recognize the need for a national commitment to solving water problems--and to take actions which back up that commitment.

He believes that commitment can best be met by openly recognizing the fundamental place that the States play in water resources, and properly identifying the Federal role as well. Then, he proposed to build the most credible and constructive Federal programs he can, programs that deserve support--from water users, environmentalists, the States, and the taxpayers.

When President Carter, in his first year in office, asked for a thorough review of national water resources policy, water technology professionals throughout the nation helped us make that review. We asked for--and got--cooperation from scientists, engineers, water managers at local and state levels of government, researchers at universities or in industrial laboratories and from American businesses. Many of you were involved in that review.

After studying the results of that review and after making his June 6 water policy statement, he issued 13 water policy directives which were aimed at improving planning and management of Federal programs, providing national emphasis on water conservation, increasing Federal-State cooperation in water resources planning, and increasing attention to environmental quality.

These directives recognized the realities of water resource economics--the increasing costs of construction for water projects, and the decreasing willingness on the part of the taxpayer to foot the bill for unwise or unsound investment in water projects which were unnecessary, wasteful, or which just didn't make sense when honestly compared to other alternatives.

The announced cornerstone of the President's policy is water conservation, and it is time that there is a major emphasis on the more efficient use of water. But in working with the policy, it is becoming clear to me that there is a better way to describe the major focus of the policy. It is simply better management.

Water conservation is, as many of you understand better than I, only a tool, not an end result. Similarly, major water diversions or storage facilities, or sensible floodplain planning, are tools for solving serious water resource problems. They are tools for management, if our State and Federal systems will work to sharpen all the tools rather than just a few.

The President wants to greatly strengthen Federal programs to give water managers and water users greater choice in how they solve water problems through nonstructural solutions, conservation, and the development of new technologies, as well as continuing strong support for water resources development.

As a result, if you stand back from the policy and examine it as a whole, I believe you will see a thoughtful attempt to strengthen all possible solutions to water resource problems, and to a faster system which allows alternative solutions (better planning, non-structural solutions, conservation, better groundwater management, water projects) to be fully developed in a credible and open system which favors the best solutions rather than the most powerful advocates.

If I were a member of this group, I believe I would be most encouraged by the general thrust of this policy because it opens the game up to the new solution, the inventive solution, the solution which is uniquely suited to the water resources problem at hand. To be uniquely suited today, it must do more than simply develop water--it must make economic sense to a business or to a local government, it must be sound economically and it should be capable of genuine public support on the basis that it solves more problems than it creates.

Many of you here are on the cutting edge of new technology or new applications which do represent new alternatives to solve water problems. The President's objective is to see that such solutions are considered and to build a system which insures that, if they are the best solutions, they will be used.

In order to accomplish this objective, the policy itself is diverse as is its implementation. Some parts of the policy require new legislation, others require new regulations under existing authority, and still others need only administrative change or the establishment of new working relationships. Nineteen task forces have been formed to carry out the President's directives with each having representatives of all Federal agencies having an interest and headed by a lead agency. The task forces are all open and public. Diverse participation is encouraged. A special effort is being made to involve state and local governments.

Each task force is responsible--under the oversight of Secretary of the Interior Andrus--for expeditiously implementing the President's water policy in an assigned area. In August and September 1978, each group held organizational meetings. A water policy coordination group in my office, headed by Mr. John Cunningham, was set up to serve as a focal point. They have recently issued their second progress report. Recommendations of these task forces are being reviewed at regional meetings and the state governments, the congress and interest groups are being consulted.

The engineers, scientists, businessmen and representatives of local, State and Federal government who are here today are all concerned about reuse. It has been said that conservation is our greatest available source of "new" water. If that is true--and I believe it is--then water reuse and recycling systems must be a major part of that new source. What do we need to do (what does the policy need to do) to accomplish this objective?

First--more dollars *are* needed--needed to do essential jobs, to take on important projects. The President's recommendations are for a comprehensive water policy which does not cost less but which makes the best choices when spending budget dollars. Among all the budgets in my area this year, the one that took a real step forward was the Office of Water Research and Technology. This was not at the expense of new construction starts either where, in two years, the President has offered more in any two-year period in over a decade. What is needed, in our views, is not great cutbacks or even vast new expenditures but a basis for making better decisions every time.

In order to assure the proper flow of capital into water resource development, some changes are needed. New political accomodations and arrangements are needed. New technology must be developed. We must find new ways of funding projects and more efficient ways of planning and administering our water programs at the Federal level.

In the area of water reuse, we need to find the answers to some basic questions. How much money does usable water really cost in various practical applications? What institutional changes are needed to make best use of available water in water-short areas? What is the role of industry in cooperating to conserve and protect water? How can the Federal Government work with local and State governments, with industry, and with the public to foster a real role for reuse technology without overreaching legitimate state, local and private prerogatives?

What this Administration is attempting to do with the water policy debate with 19 task forces, with the President's focus on water conservation and water planning and management, is to set the Federal house in order *first*, and then to improve the quality of our effort in working with *all* other sectors to accomplish the right solutions.

Let me try to bring some of the intent of the policy down to terms which are significant to this gathering. A good example of R&D investment which is working *right now* to conserve water is the water reuse and water recycling technology this symposium is discussing.

The Second National Water Assessment by the Water Resources Council, and an evaluation of reuse needs and potential done by OWRT indicate that total freshwater withdrawals of more than 362 billion gallons a day in 1975 are expected to decrease to about 330 billion gallons a day in the year 2000. This hopeful project is based upon continuing the present trends in industrial recycling and improvement in irrigation efficiency. Increasingly stringent wastewater discharge limitations, coupled with recurring drought periods in water-short areas of the country, can provide major impetus for going considerably beyond the current trends. We now estimate that the total industrial water recycling rate could increase from about 1.9 bgd in 1975 to 8.8 bgd in the year 2000. The reuse of municipal wastewaters could increase from the present relatively insignificant quantity--less than 1 bgd--to almost 5 bgd in the same period of time. This is a trend that a good policy must encourage and support.

Recent Federal legislation is expected to have a significant impact on the quality of wastewater discharges and on water reuse. The Safe Drinking Water Act (P.L. 93-523) and the Clean Water Act of 1977 (P.L. 95-217) will both result in significant improvements in the quality of wastewater discharges in many instances that will allow the incremental quality improvement which is needed for reuse to become economically feasible. This is legislation that must be support by sound administration.

In addition, the Water Research and Development Act of 1978 (P.L. 95-467) authorizes the Office of Water Research and Technology of the Department of the Interior to continue its comprehensive research and development program in water reuse. This is legislation we proposed, and aggressively pursued because it reflects exactly the emphasis on new ideas and better alternatives we intend to promote with our policy.

It is pleasing to note that this conference deals with agricultural, municipal and industrial reuse and recycling. All too often the term "reuse" is taken to mean direct potable reuse of municipal sewage effluent with all of its attendant potential aesthetic and health effects problems. While it is true that many urban areas may require some type of direct reuse in the future, the opportunities for other forms of reuse or recycle appears to be orders of magnitude larger on a national scale. It is logical to preserve higher quality water, where possible, for potable purposes while implementing reuse of wastewaters for applications having less stringent quality requirements.

There is, in the minds of some critics, at least, a question about what the administration means by water conservation. There can be lots of definitions of that word in relation to water, of course--rain barrels are probably the oldest way to save water, and for many years, people who had no other alternative thought of water conservation as something like building monstrous-sized rain barrels. But that's really not conservation, if you have to use up what's in the rain barrel every year. There are better ways, as we all know. The definition which makes sense to this Administration is simple: Demand reduction, efficiency in use, and better management of water sheds to reduce water loss by retention measures. This definition intends no violence whatever to conventional water storage nor does it propose to rewrite history or the water testbooks. It simply offers the emphasis we intend to pursue. Water storage will continue, and as I said earlier, such projects have received strong support in the last two years.

A common sense approach to water conservation is illustrated by the water reuse and recycling which is taking place in many industries today. In the final analysis, water conservation can be measured in dollars not in gallons or cubic feet. In the reviews which are taking place right now in the Department of the Interior, we insist that water conservation proposals be cost-effective. If they're not, it's back to the drawing board. I know that is the approach which you are taking too.

I am happy to see that this symposium is cosponsored by several federal agencies as well as by two of the leading professional organizations in the water resources field. The roster of speakers here today and scheduled for the next few days at this symposium is indicative of the broad participation by federal agencies and the private sector in solving water problems realistically. Close cooperation among all of those who deal with water resources planning and water management, and coordination of federal water programs in all the agencies of federal government, will be necessary if we are going to make the national water policy work. This program is indicative of the commitment I find wherever I speak to water resources people in the nation. I have spoken to you today about the first stages of our development of national water policy. Actually, much of the implementation effort is moving quite quickly, but much remains to be done, nevertheless, the President wants the Federal role to be one which compliments the basic roles of state and local governments and the many water users of the country. He wants the Federal role to be strong in seeking the best investment of taxpayer dollars and in providing the best solutions to serious water problems.

Two years ago, I said that except for energy, water would be our most pressing national resource problem. That is still true. In fact, water probably would be the more important issue if it had more "sex appeal." In 1973, we Americans were jolted into recognizing our wasteful use of energy, and overnight, energy became a priority consideration. We haven't yet had that jolt on water, but unless we continue to take sensible action, that jolt may come. Water can no longer be considered a stepchild among the resources--taken for granted and used without thought. It is a reclaimable resource of inestimable value and increasing scarcity. Like clean air, it is basic. We will pay whatever is necessary to assure an adequate supply.

That is why the topic to be covered by this symposium is so important. Water reuse is an increasingly viable method of augmenting existing water supplies, and its role in the future is unlimited. A rapidly expanding industry is being developed to produce water reuse technology. I will be interested to hear your viewpoints about what role the Federal Government should play in the growth of that industry. What involvement should the reuse technology industry have in the developing national water policy? I feel your role is essential and central to water conservation and water planning in all parts of the nation. The proceedings of these meetings will be valuable--not only to you, the participants, and to the organizations and businesses and governments you represent. They will be valuable to the members of the 19 task forces who are attempting to implement the President's water policy initiatives--and they will be valuable to every department and agency of government which has a part in water policy development.

The President's policy is one which rejects the old technique of resolving water problems through advocacy of a specific solution to a specific problem, usually an expensive and complex solution. Rather, the President's policy will ask that the Federal Government and all federal programs fully understand water problems of the nation, examine a wide range of solutions, and think of the long-range as well as the short-range water resource impacts. If I were a member of an industry which offers the promise of new and unique solutions to many water problems I would be very encouraged.

Thank you for giving me the chance to be with you today.

OWRT'S WATER REUSE RESEARCH AND DEVELOPMENT PROGRAM

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The Office of Water Research and Technology (OWRT) of the U. S. Department of Interior is authorized to conduct a broad research and development program for water reuse under the provisions of the Water Research and Development Act of 1978 (Public Law 95-467) enacted in October, 1978. Before describing the OWRT Reuse Program I would first like to present a brief overview of OWRT, it's programs and it's functions.

The Office of Water Resources Research (OWRR), one of OWRT's predecessor agencies was established by the Water Resources Research Act (P.L. 88-379) in 1964. This Act was passed to establish a partnership between the Federal government and the State Land Grant Universities through a network of university-based State Water Resources Research Institutes. The Institutes were intended to accelerate research in water resources problems and to provide training for scientists and engineers. Water Resources Research Institutes currently exist in each of the 50 States plus the District of Columbia, Puerto Rico, the Virgin Islands and Guam. In 1974 the Office of Water Resources Research was merged with the Office of Saline Water (OSW) to form the present Office of Water Research and Technology. Prior to the passage of P.L. 95-467 in October, OWRT programs were carried out under the authority of the Saline Water Conversion Act of 1971 (P.L. 92-60) as well as the Water Resources Research Act.

PROVISIONS OF PUBLIC LAW 95-467

The new Water Resources Research and Development Act of 1978 authorizes the following:

- A Water Resources Research and Technology Institute at a land grant College or University in each State, the District of Columbia, the Virgin Islands, Puerto Rico, Guam, American Samoa, Northern Mariana Islands and the Trust Territory of the Pacific Islands. Primary functions of the Institutes are to: (1) plan, conduct, or arrange for research, development, technology transfer and information dissemination; (2) arrange and conduct training of water resources scientists and engineers and (3) cooperate with other academic institutions to develop State-wide research and development programs directed at State and regonial water resources problems.

- Water Resources Research and Development Programs concerning water-related problems of national interest. These programs include, but are not limited to: water reuse; water conservation; planning; management and operations; legal and institutional arrangements; salinity management; saline water conversion; and economic, social and environmental impact assessment.

- Water Resources Demonstration Programs and activities to demonstrate technical and economic viability of processes, systems and techniques for improving water or the water-related environment. Included are research, development and demonstration programs for the conversion of saline and other impaired quality waters to beneficial use.

- A research assessment and technology transfer program to transfer research and development results to other organizations and individuals for further development and practical application to water and water-related problems.

- A national center for the acquisition, processing, and dissemination of information dealing with all areas of water resources research, technology development and demonstration.

The new Act, in summary, consolidates and expands the authority contained in the previous legislation and authorizes a broad water resources research, development and demonstration effort to be administered and directed by the Secretary of the Interior. The Department of Interior responsibilities are carried out through the OWRT.

WATER REUSE PROGRAM

As indicated above, OWRT is authorized to conduct a research and development program for water reuse and is, in fact, currently in the third year of such a program. The development of technology to economically reclaim wastewater for beneficial reuse to supplement and extend existing water supplies is becoming a key element in fully utilizing our limited water resources. We are now starting to realize that water is a reclaimable resources and its efficient reclamation and reuse is becoming a vital short-term consideration in many water-short areas of the United States. Until recently water reuse was not considered an important factor in industry location or design of industrial process equipment. Other factors such as labor availability and transportation were more important in industry management decisions. Water supply and reuse resulting from increasing competition for available fresh water supplies are now beginning to have a major impact on industrial economics resulting from passage of Public Law 92-500 and Public Law 95-217. Both industries and municipalities are now required to treat wastewaters at considerable costs to meet discharge limitations. In some instances, the required quality of treated water is now or soon will be adequate for many reuse applications. In many other instances additional treatment is necessary to meet reuse requirements. Some of the factors which now must be examined when considering the economics of reuse include:

- Costs of treating wastewater streams to reuse quality.
- Costs of water from alternative sources.
- Costs of treating wastewater to meet discharge requirements.
- Economic value of recovered by-products or wasteheat.
- Total energy requirements.
- Reduction of freshwater requirements.
- Pretreatment costs and municipal sewerage charges.

Reuse Program Objectives

Projections of gross water use and reuse potential are shown in Figure 1. Figure 2 indicates projected total usage by major water using sectors. The objective of the OWRT Water Reuse Research and Development Program is to identify and seek solutions to both technological and non-technological barriers to water reuse. The program is focusing upon planned beneficial reuse of wastewaters from the following sources:

- Municipal Wastewaters
- Industrial Process Wastewaters
- Cooling Water
- Agricultural Wastewaters (Irrigation return flows).

Potential reuse applications being considered under the program include:

- Groundwater Recharge
  - Aquifer Recharge
  - Saltwater Intrusion Barrier
- Irrigation
- Industrial Water Supply
  - Cooling Water
  - Process Water
  - Boiler Feedwater
- Recreation
- Aquaculture
- Domestic Water Supply
  - Potable
  - Non-Potable.

OWRT was first authorized to conduct a comprehensive water reuse research and development program starting with U.S. fiscal year 1977 (beginning October 1, 1976). Approximately $1.7 million was appropriated for this program in FY 1977 with an additional $3.3 million appropriated for FY 1978 and $3.4 million for current FY 1979. We have attempted to formulate our program so as to avoid fragmenting our limited resources and to also avoid potential duplication with other Federal agencies. The primary thrust of the OWRT program is on planned beneficial reuse of wastewaters rather than on pollution abatement to meet regulatory requirements. Although the current "direct" and "indirect" reuse terminology has created some confusion, we are focusing upon direct reuse wherein the wastewater stream generally retains its identity in the reuse application. Our industrial reuse research and development efforts are being focused primarily upon the high water using industries such as: Paper and Allied Products (SIC 26); Chemical and Allied Products (SIC 28); Petroleum and Coal Products (SIC 29); Food and Kindred Products (SIC 20); Primary Metals (SIC 33)and Textile Mill Products (SIC 22). These six industries presently account for almost 90 per cent of the total national fresh water withdrawals from manufacturing industries. Our current lowest priority is for direct pipe-to-pipe potable reuse. This low priority is due to the extensive health effects research associated with potable reuse, the lack of potable quality standards where wastewater is used as the raw water supply, the extensive potable water R&D efforts by EPA and the relatively small projected potential need for direct potable reuse. The OWRT Reuse Program is initiated each year by the issuance and publication of a solicitation for proposals along with a set of research and development priorities. Notification of the availability of these priorities is published in the Commerce Business Daily (CBD) and the priorities are sent to those responding to the CBD notice and to others on our mailing list who have indicated an interest in reuse research and development. Typically 150 to 200 proposals are submitted to OWRT in response to these priorities. Proposals may be submitted by any individuals or organizations having water research and development capability inculding educational institutions, private foundations and institutions, private firms and individuals, and local and State agencies. Projects are selected for funding support from these proposals. The OWRT program is coordinated with the other Federal agencies having interest in water reuse. For example, a copy of every proposal received is sent to EPA for supplemental technical review and to avoid potential duplication. Copies of proposals are sent for review to other Federal agencies such as the Department of the Army, and Department of Interior agencies such as the Geological Survey and the Bureau of Reclamation if the subject matter is within their general area of interest and expertise. For example, proposals dealing with reuse for groundwater recharge would be sent to the Geological Survey. In several instances OWRT is jointly sponsoring projects or other reuse efforts with other Federal agencies. This National Reuse Symposium is a joint effort of four Federal agencies (OWRT, EPA, DA, NSF) as well as the AWWA Research Foundation and WPCF. A reuse R&D project at the Reigle Textile plant in South Carolina is being jointly sponsored by EPA, DOE, and OWRT.

Current Efforts

Current OWRT reuse efforts are in four basic categories described as follows:

Evaluation of Reuse Needs and Potential.

Studies are on-going and planned to assess the potential magnitude of wastewater reuse and recycling that may be required or feasible to augment existing water sources. These studies will identify major areas of wastewater reuse needs and potential and will enable OWRT to adjust research and development efforts to meet specific needs. The results of these studies will enable us to establish priorities that hopefully will have maximum impact on potential reuse and recycling. A brief description of some of the key current efforts in this field follow:

Evaluation of National and Regional Water Reuse Needs, Potential and Treatment Technology. This project now being completed by the firm of Culp/Wesner/Culp will provide a major national evaluation of water reuse and recycling potential projected to 1985 and the year 2000. We consider one portion of the study to be analagous to a water reuse "market survey". The study analyzes the need and potential for municipal, industrial and agricultural reuse for each of the 21 Water Resources Council Regions of the United States. The second portion of the study evaluates the effectiveness, costs, energy requirements and other aspects of conventional and advanced wastewater treatment processes and systems. Different combinations of treatment processes are combined to achieve optimum systems to provide a degree of treatment necessary to meet the water quality requirements of various reuse applications. Biological and physical-chemical processes up to and including reverse osmosis are included in the study. We are extremely pleased with the outcome of this project and expect the two volume report to become landmark references in the field of water reuse.

Evaluation of the Application of Desalting Technology for Treatment of Wastewaters for Reuse. This study scheduled for completion in 1979 by Tours Corp., will provide an evaluation of the demineralization processes for reuse similar to the Culp study noted above. The study will characterize the technical and economic factors of electrodialysis, freezing, distillation and other so-called desalting processes with the exception of RO.

Evaluation of Reuse in the Steel Industry. The Primary Metals Industry (SIC 33), withdraws about 18 bgd of fresh water or about 34 per cent of the total water withdrawals by manufacturing industries in the United States. The Blast Furnace Steel Products (SIC 331) portion of the industry alone withdraws over 15 bgd. OWRT has contracted with Hydrotechnic

Inc., for a detailed evaluation of current and potential reuse and recycling within this industry. This on-going study is evaluating water requirements of various steel plant processes, treatment, discharge requirements, dissolved solids buildup, and other considerations impacting reuse. The study will ultimately define major reuse/recycling opportunities and directions for future reuse research and development.

Evaluation of Treatment Technologies for Water Reuse in Coal Gasification.

This research project by Carnegie-Mellon University will study recycle strategies and will include bench-scale testing of various treatment schemes using actual process wastewaters. Treatment investigation will include oil separation, dissolved gas removal, phenol removal and recovery, chemical and biological oxidation, nitrification-denitrification, trace metals removal and demineralization. This potentially major future industry will undoubtedly use significant quantities of water and we now have an opportunity to possibly reduce future water withdrawals and alleviate the competition for limited water resources in areas of the country where energy conversion could become a major industry.

Treatment Processes and Systems

OWRT is supporting research to improve existing treatment technology and develop new processes for renovation and reuse of wastewater streams. Our primary emphasis is on new innovative processes and adaptation of demineralization processes. A brief summary of our current efforts in this area is as follows:

Membrane Processes

- Development of open-channel spiral membranes for reuse.
- Effects of pretreatment chemicals on reverse osmosis membranes.
- Evaluation of hollow-fiber membranes for reuse in metal finishing and textile industries.
- Use of coupled transport membranes in the Primary Metals Industry.
- Ferric ion colloid pretreatment for wastewater reuse in reverse osmosis systems.
- Evaluation of commercial semi-permeable materials for potential ultrafiltration and electrodialysis membranes in reuse applications.

Adsorption and Oxidation Processes

- Evaluation of biological activated carbon for reuse.
- Lime clarification and pressure ozonation for reuse.
- Weak-electrolyte ion-exchange performance.

Innovative Processes

- Multi-species aquaculture (water hyacinths, duckweed, shrimp, fish) low energy system for wastewater treatment, reuse and recovery of biomass.
- Water reuse hatchery system for smolt production.
- Solvent extraction system for industril reuse using liquid ion-exchange impregnated polysulfone microporous beads.
- Micro-Gas-Dispersion process for renovating and reusing industrial wastewaters.

Municipal/Industrial Applied Research

This segment of the OWRT Reuse Program supports applied municipal and industrial reuse projects having significant research and development efforts. Priority is given to high water using industries including reuse of wastewater from other sources well as internal industrial recycling. Municipal reuse emphasis is on groundwater recharge and reuse as industrial cooling water. Our major current efforts in this field include:

Water Reuse Through Groundwater Recharge in Illinois. The University of Illinois and the State of Illinois are investigating recharge of a shallow aquifer using high quality effluent from the Chicago Metropolitan Sanitary District. The project will include complete monitoring of the fate of trace organics, heavy metals and viruses as they travel through the soil strata and the aquifer.

Evaluation of Membrane Demineralization Processes for Wastewater Reuse.

This project is providing support of the well-known Water Factory 21 project in Orange County, California. Information and data on this project has been widely presented and published and details are available in the literature. OWRT is primarily interested in evaluation of cost and operational data from the 5 mgd reverse osmosis plant as well as experimental work on various membrane processes and material treating small sidestreams taken from different points of the main treatment facility.

Closed-Cycle Textile Dyeing Demonstration. Research is being conducted for large scale, high temperature reverse osmosis system to achieve closed-cycle operation of a textile dyeing process at the Reigel Textile plant in LaFrance, South Carolina. This project, jointly supported by EPA, DOE and OWRT, is not only evaluating the recycling of process water but also the recovery and recycling of energy, chemicals and the impact of recycling on pollution abatement.

Research and Development of Advanced Processes Using a Mobile Treatment Unit.

OWRT has contracted with Envirex for fabrication and operation of a mobile treatment plant for testing feasibility of industrial water recycling. The mobile unit includes advanced processes such as electrodialysis, reverse osmosis, and ion-exchange in addition to a variety of pre-treatment processes. The mobile unit is testing the effects of the various treatment processes on industrial process effluents and equally important, the effects of the wastewaters on the treatment processes. For example, data from this effort should indicate whether membrane processes can be directly used for recycle of industrial wastestreams or whether such factors as chemical or biological degradation, compaction, or low flux rates indicate that additional R&D efforts are required for the processes. The mobile unit has already operated at a paper mill and a food processing plant and is currently testing at a chemical manufacturing plant in Texas.

Other OWRT applied research and development projects which have just recently started include the use of biologically extended activated carbon (BAC) by the University of North Dakota for reuse of food processing wastewaters and a project by Georgia Institute of Technology for decolorizing textile process waters by ozonation and ultraviolet light.

Planning and Management Aspects of Reuse

In many instances social, legal, economic and institutional barriers to water reuse are at least as significant as the technological barriers. We are therefore supporting research to clearly identify non-technology barriers and potential alternative solutions. Current key projects in this field include:

Public Evaluation of Wastewater Reuse Options in Basin Planning. The State of California and the University of California are investigating public views of actual wastewater disposal and reuse alternatives being considered within the State. Although several studies of this general nature have been conducted in the past, this project is unique in its consideration of actual options and a population that has experienced a severe water shortage in the past two years.

Overcoming Legal and Institutional Barriers to Consumptive Reuse of Low Quality Water in the Colorado River Basin. This study by the Denver Research Institute is investigating legal, institutional, and political barriers and alternative solutions to water reuse within the seven states of the Colorado River Basin. The project includes research into state and inter-state water allocation law and Federal and state environmental law to identify legal barriers to reuse. The project includes case studies of actual and proposed reuse projects to establish the relationships between reuse barriers and incentives in real situations.

The Input-Output Water Balance Model Application to Water Reuse Planning.

This research by Colorado State University is studying the application of input-output water balance models to regional water use planning. Data is being taken from other models to identify reuse alternatives and relate them to planning objectives within the contex of a large complex water resources system. We are hoping that the output from this project will serve as a guide for application of input-output models to water reuse planning studies in other areas.

Other OWRT supported research projects in this field include studies by U.C.L.A. and David Dornbusch Co., into legal, institutional, and political reuse obstacles in California and other areas of the western United States and an investigation by James Montgomery Consulting Engineers into economic tradeoffs involved in widespread implementation of industrial use of reclaimed water.

Current OWRT Reuse Research and Development Priorities for FY 1979 have been published and are available. Briefly we are seeking the following types of projects:

- Additional detailed studies of high water-using industries to identify recycle potential and treatment requirements.

- Treatment processes and systems with emphasis on innovative processes and adaptation of desalting processes for wastewater reclamation and reuse.

- Research into the economics of using reclaimed wastewaters including user damages and determination of reuse benefits.

- Methodologies for determining and planning subsequent uses of previously used waters.

Our Reuse Program is now well underway. We currently have about 40 projects in various stages of completion. Our program is comprehensive in scope and, as I noted previously, is open to all qualified organizations and individuals including academic institutions, consulting engineering firms, private research organizations, industries and public agencies. We can provide details of our current research and development priorities or information concerning our current projects to those with specialized interests.

Our program is a national one - I encourage you to participate in it.

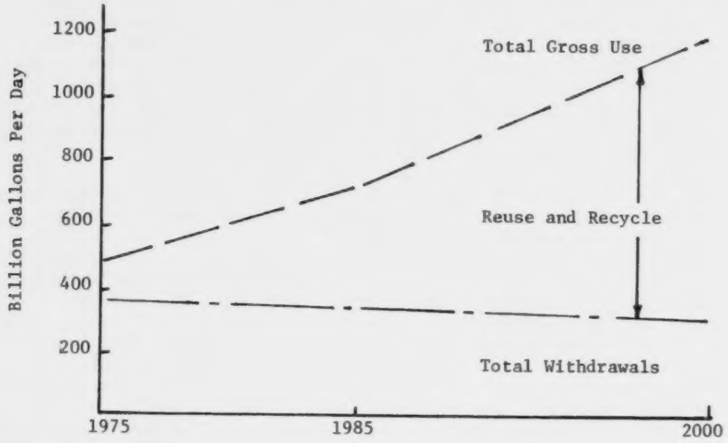

FIGURE 1
PROJECTED REUSE AND RECYCLE

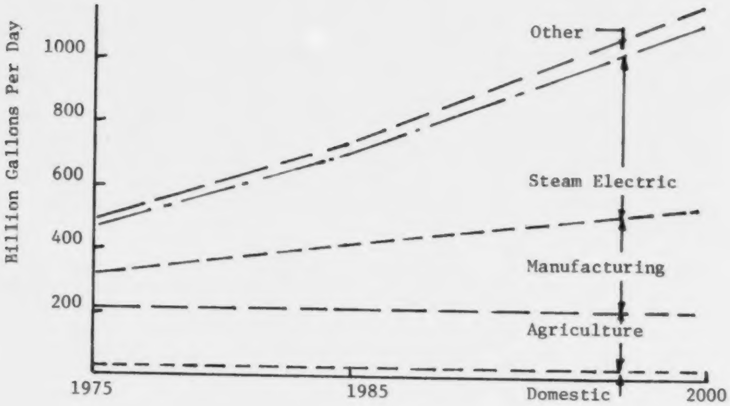

FIGURE 2
NATIONAL GROSS WATER USE

WATER REUSE: IT IS TIME FOR IMPLEMENTATION

Thomas C. Jorling
Assistant Administrator for
Water and Waste Management
U. S. Environmental Protection Agency

I am pleased to be here to report on EPA's progress in implementing water reuse, which I believe is a basic tenet of the Federal Water Pollution Control Act and its successor, the Clean Water Act (CWA). We have made great progress in this area in the last two years and I believe this will continue. There is increasing recognition at every level of society that water reuse is a fundamental component of the wise and efficient management of an increasingly scarce, but essential, natural resource. I will begin by discussing some of the factors that led to this surge of activity.

The 1972 Amendments to the Federal Water Pollution Control Act represented an important shift in national policy towards water reuse. Prior to those Amendments, the nation's waters were regarded both as inexhaustible sources of water to be developed and as pollution sinks. Few people recognized the relationship between related withdrawal rates and temperature increases or salinity intrusion. The ability of a water body to sustain beneficial uses was measured only in such terms as dissolved oxygen and assimilative capacity. The limitations of such measurements reinforced a simplistic "out-of-mind" attitude which allowed any feeling of personal responsibility for the safe disposal of sewage to end at the treatment plant, which, of course, did not discharge in proximity to the community. One of the major constraints to effective implementation of water reuse has been the aversion to any kind of identifiable association with human waste within our immediate environment. Ironically, this concern has not extended to the transmission of the wastewater to other people's environments. Thus, an upstream community has rarely exhibited concern over transferring its waste products, treated or otherwise, to residents downstream. This irony has been further manifested in the concerns often expressed over the long-term health effects of proposed land treatment projects, even in areas that would have been closely confined and subject to careful monitoring. These same concerns were infrequently voiced over the long-term health or ecological effects of discharging wastewaters into the stream, rivers and lakes where its migration and bioaccumulation in aquatic organisms was seldom if ever monitored. I have used the past tense in this discussion because I believe that a threshold of knowledge, responsibility and acceptance has been passed in recent years.

A number of things have led to this change. Foremost has been the experience of a series of droughts in the mid-seventies which taught us that our best laid plans for water storage are no match for nature's uncertainties. We are reminded almost daily that water is not an inexhaustible resource. Reports of steadily declining aquifers and completely appropriated streams flows mount on the one hand even while the memories of recent droughts have not faded. Studies at every level demonstrate this to be a major national problem and point toward the inadequacy of conventional, technological solutions. We are running out of acceptable reservoir sites and areas with surplus water for inter-basin transfers. The marginal costs for newly developed water have increased enormously in recent years. Even so, the full effect is not yet upon us. The growth of our energy, industrial, agricultural and municipal sectors is predicated on new sources of water being developed. If not addressed quickly the situation may erupt into an economic and legal competition. As an example, there is already intensifying competition in the Rocky Mountain states between water intensive energy and agricultural interests. These growing conflicts, unless addressed may lead to social and economic displacements. The future growth and direction of the nation and the quality of the environment is increasingly centering on the relative availability of the most essential of all nature's resources - water. Moreover, rapidly increasing information on toxic organic pollutants, as expressed for example in drinking water standards proposed last year, coupled with spiralling costs associated with advanced wastewater treatment facilities have resulted in a re-evaluation of our initial rush toward sophisticated end-of-pipe treatment technology as the ultimate answer. Environmental statutes have steadily eliminated those remaining unregulated waste disposal practices which previously have been cheaper although more environmentally harmful than land treatment. User charges now more accurately reflect the true environmental costs of waste disposal and will increasingly inspire water reuse and recycling. I expect that reclaimed water will increasingly become too valuable a commodity to simply use once and dump. Moreover, reclaimed water supplies are much more reliable than stream flows which vary seasonally and may be non-existent during droughts. Reclaimed water also is a source of nutrients for irrigation especially as energy costs drive up the cost of traditional fertilizers.

The President and the Congress have both emphasized the importance and the need for water reuse. The President's water policy of last June sets out water conservation as its cornerstone. The President and the Congress, in passing the 1977 Amendments to the Clean Water Act, clearly set forth a policy that water reuse is to be more aggressively implemented. Tomorrow Mr. Alan Hais of EPA's Office of Water Program Operations will provide details on the provisions of these Amendments and EPA's responses. But I wish now to highlight section 201(g)(5) of the Clean Water Act which states that a construction grant shall not be made "unless the grant application has satisfactorily demonstrated to the Administrator (of EPA) that innovative and alternative wastewater treatment processes and techniques, which provide for the reclaiming and reuse of water...have been fully studied and evaluated by the applicant."

One EPA role in this objective, and it is a shared role, is to promote the construction of wastewater treatment systems involving water reuse and recycling. The Agency has responded to these Congressional and Executive directives and will continue to review its programs to see if it can do more. Even prior to these directives, the top management of EPA made a strong commitment to encourage and facilitate the selection of land treatment and other reuse and recycling options. In October 1977 the Administrator of EPA issued a policy calling for the Agency to "press forward vigorously for publicly owned treatment works to utilize land treatment processes" as a part of an overall water reuse strategy.

EPA has two other important roles in water reuse implementation. First, it is attempting to merge water quality and quantity in its water planning activities. Our reasons for this are straightforward; increasing expenditures for end-of-pipe water pollution control make little sense in a system where increased withdrawals will make it impossible to maintain ambient conditions. In such situations water reuse, together with water conservation, are increasingly the only realistic alternatives for an area to maintain some level of continued growth while maintaining the quality of its natural environment.

Second, under the Safe Drinking Water Act, EPA is charged with protecting the health of consumers of drinking water. Many questions remain on the feasibility and reliability of potable reuse. Until these questions are answered, EPA must oppose direct potable reuse unless under exceptional and very carefully controlled situations. However, I believe that in almost all cases the same end results can be obtained through source substitution. Source substitution, or source matching as some term it, involves the use of lower quality reclaimed water to meet existing non-potable demands so that high quality fresh water withdrawals may be reassigned to meet present or future potable demands. As an example, I would like to cite the case of Northglenn, which is a city near Denver in Colorado. A multipurpose water resources project has been proposed by the city which would consist of facilities for drinking water supply, wastewater collection and treatment, supplemental groundwater pumping, and urban runoff collection. An agreement between the city and an irrigation district has been signed that allows the city to utilize water appropriated and stored by the irrigation district in a reservoir for potable use in return for a 110% return of that volume of water to the irrigation district. This 110% return will be made up of treated wastewater, urban runoff and groundwater. This innovative project will allow municipal and agricultural needs to be met without compromising public health.

Source substitution is not a new concept; however, because of existing water law and customs, institutions, economics and water law implementation has been nearly what it might be. Federal and State economic incentives lie predominantly on the side of development of new water resources. These subsidies have included grants and low interest loans or even direct Federal construction of water supply reservoirs, inter-basin transfer projects and new or deeper wells to chase falling water tables. In some parts of the country, these subsidies have resulted in new water being more inexpensive than reclaimed water or water conservation measures. Unless modified, continued subsidies of new water development will remain a major impediment to implementation of water reuse projects. One of the task forces created to implement the President's water policy is analyzing alternative water pricing policies. These changes, combined with the economic incentives already provided in the Clean Water Act, could result in the economics of water reuse becoming more favorable.

The separation of water resource and water quality institutions at all levels of government has also impeded implementation of water reuse. EPA is addressing this in a number of ways. First, through modification of its water quality management regulations to include water quantity considerations. Second, through the issuance of guidance for the development of agreements between each State and EPA for the receipt and use of program grant funds. These agreements provide a means for integrating and coordinating State and EPA environmental management programs. Third, by preparing two studies which will provide Congress and the States with options and recommendations for coordination and integration of these programs. The first of these studies is the Water Allocation/Water Quality Coordination Study which is to be completed in June of this year. The second is the Water Supply/Wastewater Coordination Study which is to be completed in December of this year.

Water law has also moved slowly to address source substitution. It has been used by those with rights to high quality water as a protection to maintain the best quality water available, regardless of the quality needs of the use. While at one time plentiful water resources may have been able to accomodate this, I believe this time has passed. The liabilities of other potential responses, such as potable reuse and new water development are significant. I am pleased to note that a number of states have established commissions and other means of re-examining their water law.

In the last seven years EPA has sponsored a substantial amount of research, demonstration and full scale non-potable reuse projects. These projects have provided a significant body of data on the feasibility, economics, health effects, and reliability of non-potable reuse projects. These projects have demonstrated the natural cleansing capabilities of the soil mantle. EPA has additionally instituted a national pretreatment program to control toxic pollutants at the source, thus reducing the concentrations of contaminants that might otherwise preclude certain reuse options.

Despite this, conventional responses to the types of water quality and water quantity problems I discussed earlier may be easier to implement than innovative and alternative solutions, such as water reuse. The institutional relationships and engineering may be much simpler, the risk level for engineers and elected officials lower and the implementation timing shorter. But conventional responses are generally incapable of protecting the total resource. Their viability is dependent on structuring "problems" in a very narrow, and as we now know, unrealistic manner. It is a challenge to all of us to not take the easy path.

While it is the Agency's policy to take an affirmative posture toward these emerging initiatives in water reuse we cannot be indiscriminate. Some projects will be ill advised--too costly, poorly located, inadequately designed or just the wrong option for the area's wastewater treatment needs. Cost-effectiveness, protection of ground water and the overall concerns for public health will not be ignored in our efforts to advance this initiative.

Where questions remain, principally in the area of potable reuse, we have and must continue to develop the data with which to move ahead or to make decisions on future implementation. Even now EPA is moving to develop potable reuse criteria, although this will likely take a number of years. I believe that at the end of the next five days you will recognize that we have come a long way. You will also recognize a little better what questions remain and what must be done to resolve them.

As I stated at the outset, water reuse is more than an EPA priority, it is a fundamental tenet of water quality management. Water reuse is the option of choice in the construction grants program and the burden of proof lies with those who would support conventional alternatives. The constraints to full implementation of non-potable water reuse lie largely outside the research and development arena. They are not insurmountable. Where they exist, we must initiate the process that will bring about the necessary change. The implementation of water reuse will continue to represent a challenge demanding our joint efforts. EPA is committed to its success.

THE ENVIRONMENTAL PROTECTION AGENCY'S RESEARCH PROGRAM FOR WATER REUSE

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I am pleased to be able to present to you today a brief description of the Environmental Protection Agency's research program in wastewater reuse in municipalities, industries, and agriculture. The program's past accomplishments have given the impetus for promoting much of the new technologies and current practices in use today. Achievement of our present research objectives will result in an even greater impact on water reuse in the future.

WATER REUSE IN MUNICIPALITIES

In the municipal research area, the major goal is to prove the feasibility and practicability of reusing municipal wastewaters through research and experimental demonstrations. This includes source substitution to conserve high quality supplies, direct potable reuse, indirect reuse for domestic purposes through recharging of surface and groundwaters that serve as drinking water supplies, and water conservation techniques.

The components of the Environmental Protection Agency involved in this program are the wastewater and water supply divisions of the Municipal Environmental Research Laboratory (MERL) in Cincinnati and the Health Effects Research Laboratory (HERL), also in Cincinnati; both of which are in the Office of Research and Development (ORD).

Past and Current Activities

The Municipal Environmental Research Laboratory has, for two decades, been involved in the development and demonstration of advanced wastewater treatment processes capable of producing effluents of high quality suitable for a range of reuse or recycling applications. The treatment technology capability can be identified for reuse applications such as agricultural, recreational, and industrial, where quality requirements have been defined. Treatment technology capability exists for many reuse purposes, with the primary exception being potable reuse. Since there are unresolved public health questions in this country on the required degree of treatment for potable reuse, the necessary treatment technology is less well defined for this purpose than for other reuses.

The emphasis on reuse and the need for reuse in this area has come about as a result of the potential availability of highly treated wastewaters that are "too good to throw away." These waters have, quite naturally, attracted attention in water-short areas.

Congress recently re-emphasized its interest in potable reuse in Public Law 95-477, the Environmental Research, Development, and Demonstration Authorization Act of 1979, by appropriating $8 million to expand this program in FY 79. We are currently concentrating on a new potable reuse demonstration initiative, which includes $7 million for a direct municipal reuse project at Denver, Colorado, and

$1 million as the first increment of an evaluation program to be carried out at municipal wastewater treatment sites already producing high quality water.

The project proposed by the Denver Water Board provides for design and construction of a one million gallon per day potable reuse demonstration plant that will take advantage of the most recent advances in reuse technology. The project will also include the most complete health effects program ever considered in relation to reuse. Negotiations on a $22 million, eight year effort are proceeding. We anticipate a cooperative agreement will be signed in the spring of 1979.

The $4 million, five year program will take advantage of existing municipal treatment facilities producing high quality water to provide information on the feasibility of potable reuse in systems less sophisticated than that planned for Denver. The details of this program will depend to some degree upon responses to a November 24, 1978, advertisement we placed in the Commerce Business Daily. The responses are due by late March 1979. It is expected that the program will include a thorough evaluation of the treatment effectiveness and system dependability at several sites. Associated health effects studies are expected to provide useful input for the design of the Denver demonstration.

Other FY 79 extramural funds will initiate a project to identify and assess technology for removing trace organic residues in AWT system effluents which might otherwise limit reuse.

Future Research on Municipal Reuse

The Agency's municipal reuse research program will probably continue to follow two approaches. The first is the more near-term, less controversial, nonpotable use of wastewater. The goal of this program is the establishment of feasible methods to extend valuable water supplies by source substitution. The goal should be achieved by 1984. Potential near-term nonpotable research projects to accomplish this goal are:

- Identify applications for the reuse of wastewater and development of institutional arrangements for bringing reclaimed water into our systems;
- Determine the ability of potential users (e.g., industry) to adapt to various water qualities;
- Evaluate dual distribution systems and economic incentives to promote their use;
- Evaluate the potential of and economic incentives for reuse as an alternative to costly treatment to meet stringent discharge requirements; and
- Determine the impacts of water conservation on reuse and optimize the trade-offs between these water resource management alternatives.

The second promising approach is to undertake experimental demonstrations that prove the feasibility and practicability of reusing wastewaters for potable purposes. As I indicated, we initiated those efforts this year and anticipate that we can achieve this goal by 1987. We are coordinating these activities with related water supply and health effects research programs in EPA and with State and local reuse agencies and with international organizations. Potential research projects, in addition to the City of Denver's potable reuse project, are:

- Assess, on a very selective basis, new highly promising technology;
- Investigate large-scale treatment systems for the reliable removal of potentially harmful residues;
- Cooperate with the Health Effects Research Laboratory to assess toxicological risks of ingesting wastewater residues;
- Develop monitoring techniques for regulatory programs; and
- Study socio-economic aspects of potable reuse.

INDUSTRIAL REUSE RESEARCH

In the industrial area, the goal is the control of water pollutants through attainment of zero discharge of pollutants by 1985, as mandated by the Clean Water Act. Reuse and recycle of water and pollutants is the most viable way to meet this goal. Additional benefits of reuse/recycle systems include: (1) reduction of wastewater volume, (2) reduction of intake water, (3) cost and energy savings, (4) conservation of water and other natural resources, and, last but certainly not least, (5) containment of both conventional and toxic pollutants.

The industrial wastewater research program is conducted by the Industrial Environmental Research Laboratories (IERL) located in Cincinnati, Ohio and Research Triangle Park, North Carolina, with support from the Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma. The Cincinnati laboratory's efforts are concentrated in the following industries: organic chemicals, inorganic chemicals, metal finishing, nonferrous metals, food processing and wood products. The RTP laboratory's efforts are concentrated in the iron and steel, textiles, and agricultural chemicals industries. The Ada laboratory's efforts are concentrated in the petroleum refining and petrochemical industries and combined industrial-municipal waste treatment.

Past and Current Activities

The development of reuse technology has always been an important part of our industrial wastewater research program. In the metal finishing area, we have attempted to maximize recycle in the electroplating process. We have demonstrated reverse osmosis membrane technologies on wastewaters with pH range of five to ten, two currently commercially available evaporation techniques, and special rinsing techniques for electroplating wastewaters.

We have developed preliminary engineering designs which would permit five specific steel plants to meet zero discharge of pollutants. This study, which identifies technologies to be used and their costs, also points out problem areas that must be addressed before total recycle can be a reality. For the food industries, we have shown that a biologically treated, filtered, and disinfected fruit processing wastewater could be reused for raw product conveying, washdown of equipment, floor and gutter washdown, direct contact container cooling, and boiler feed in a cannery. Finally, we have assisted a wood treating plant in developing a treatment system with no wastewater discharge. In this system, concentrated solutions of process chemicals are returned to unit operations and filtrate from a reverse osmosis unit is used as boiler feed.

We are currently giving high priority to the development and demonstration of reuse-recycle technology in several areas. One project is studying the state-of-the art in industrial wastewater and residue recycle/reuse in the organic chemical industries covered by the NRDC Consent Decree. An extensive literature search of foreign and domestic sources has so far identified twenty case studies, some of which utilize zero discharge.

In metal finishing, we are documenting the results of the HSA electrochemical reactor demonstration aimed at improving the recycle of electroplating wastewaters through in-plant changes at ten U.S. electroplating shops. The HSA electrochemical reactor demonstration,which is still underway, should provide a technology that can be utilized by many electroplaters for recycling wastewater.

For the food and wood products industries, we are investigating the simultaneous removal of total suspended solids and organic pollutants through precoat filtration utilizing diatomaceous earth/powered activated carbon on the effluent from pulp and paper mills, leather tanneries, and textile plants. The upgraded effluent would have a greater potential for reuse.

In the steel industry, it is obvious that treatment technology is not currently available to clean many of the waste streams in a steel plant. There is also insufficient information on cost, space requirements, energy requirements, etc., of potentially useful technology. We are attempting to identify potentially applicable treatment technologies by conducting pilot plant treatability studies and by evaluating exemplary foreign treatment processes. We are particularly concentrating on coke ovens and blast furnaces, especially ones located in water-short regions.

Future Industrial Reuse Research

Next year, the Office of Research and Development will initiate a multimillion dollar program for the development and demonstration of reuse and recycle options for industrial wastewater discharges. Initially this effort will concentrate on three of the twenty-one industries suspected of contributing a large number of the 129 priority (those named in the NRDC Consent Decree) pollutants in their discharge. We are now seeking $4.3 million from Congress so we can begin this exciting program in Fiscal Year 1980.

This new effort will incorporate existing treatment methods and new technologies in demonstrations of reuse and recycle systems for the selected industrial segments. Criteria for selection of industrial areas to be covered will include, but not be limited to: (1) water consumption, (2) presence and quantity of toxic pollutants, (3) growth rates, (4) existing reuse/recycle practices, (5) technology transfer, (6) economic and energy considerations, (7) project cost, (8) conservation considerations, and (9) probability of success. It is hoped that the availability of resources in future years will allow for the continuation and expansion of this program at a rapid enough rate to materially assist most industrial sectors needing assistance to meet the national goal of zero discharge of pollutants.

AGRICULTURAL REUSE RESEARCH

In the agriculture area, the major goal is to develop and demonstrate technology for the recycle and reuse of wastewater through land application techniques. The major focus here is to provide design information for construction of publicly-owned treatment works that use land application or soil treatment as an alternative waste management system. The new Clean Water Act amendments have given new emphasis to the use of land application systems, as indicated yesterday by Tom Jorling. The research is conducted by the Robert S. Kerr Environmental Research Laboratory. That laboratory has also initiated a program on the use of aquaculture techniques for the treatment of wastewater and subsequent production of high quality water for reuse.

Past and Current Activities

Existing land application systems represent a mix of conceptual designs ranging from the older "disposal" practices to the newer "reuse" approaches. Much of our historical information on system performance has been qualitative rather than quantitative. By pooling the historical experiences with newly generated quantitative data to identify best available designs, we were able to publish the comprehensive Process Design Manual for Land Treatment of Municipal Wastewater. This manual was jointly sponsored by EPA and the U. S. Army Corps of Engineers and also involved participation of the U. S. Department of Agriculture. The Ada researchers have also developed a mathematical model for predicting the phosphorus sorption capabilities of various soil types used for treatment of municipal wastewaters and have published the first comprehensive state-of-the-art review of wastewater aquaculture.

The current program emphasis is on long-term effects of soil treatment systems including plant uptake of metals and transport of nutrients. A major new project demonstrating the application of wastewater to agricultural land has been recently initiated at Lubbock, Texas. The project, which will require about six years to complete, will conduct a side-by-side comparison of the latest soil treatment technology with a similar facility which has been in service for more than 40 years. This $9.5 million project is expected to help resolve many of the potential health and environmental effects issues.

A modest program in wastewater aquaculture initiated last year includes development of design criteria for treatment systems using water hyacinths and feasibility studies on using fish to clean up or "polish" lagoon effluents.

Future Agricultural Reuse Research

In the future, the soil treatment program will develop management practices for irrigation wastewater treatment systems for use in colder climates, complete nutrient management models for nitrogen and phosphorus, and begin working on the Process Design Manual update. We will also be putting increased emphasis on determining the fate of toxic chemicals in land treatment systems. The aquaculture program will continue work on macrophytes (large leaf plants) and begin to evaluate use of other natural systems, such as wetlands, for wastewater pollution control.

RESEARCH ON HEALTH EFFECTS OF WATER REUSE

In the health effects area, the research program will evaluate the potential health effects associated with reuse of highly treated waste-water for potable purposes, with the ultimate objective being to develop the data base necessary to recommend criteria for such use. In addition, health effects data will be provided to assist in determining safe practices, proper management and criteria which are protective of public health when wastewaters are applied to land. The program is conducted by the Health Effects Research Laboratory in Cincinnati, Ohio.

Past and Future Activities

The research program for direct reuse of wastewater for potable purposes, which was initiated five years ago, has emphasized the testing of effluents from advanced wastewater treatment plants. The organics found in such effluents have been chemically analyzed and, upon concentration, have been tested for mutagenicity and chronic toxicity. Most organic compounds found to date have been in the parts per trillion range. About 20 percent of the concentrates have caused mutagenic responses in *in vitro* screening tests. In short-term animal studies significant adverse effects have not however, been found.

The HERL researchers have studied the contaminants associated with both direct and indirect reuse of municipal wastewaters and have shown that the potential problems of the two approaches are similar. They have evaluated the safety of wastewater recycle in two food processing projects and have indicated that recycle could be accomplished without compromising the quality of the food product. Finally, they have extensively investigated the microbiological aspects of wastewater reuse, determining that viruses will penetrate soils under certain conditions and that aerosols from spray application can contain pathogens which may travel considerable distances from the spray site. However, with proper management of the site and the application technique, they have found that the health risks from such techniques may be kept to an acceptable level.

The current health effects research efforts, totalling about $2 million in this area, is increasingly focusing on human exposure and effects. An epidemiological study is being initiated at a California location where an aquifer used for a community water supply has been recharged with treated wastewater for the past seventeen years. Long-term studies using laboratory animals fed concentrated effluent from an advanced wastewater treatment plant effluent are being undertaken. The animals will then be sacrificed and checked for chronic health effects. We will also continue to identify organic chemicals in wastewater, as well as to develop rapid toxicity screening techniques for those effluents. Criteria for short-term use of renovated wastewater for potable purposes will be developed for us by the National Academy of Sciences.

In the land application area, the emphasis on microorganisms, including those that cause viral gastroenteritis, transported by aerosols or through the soil is continuing. The minimum infective dose of the enterovirus ECHO-12 in a group of human volunteers will be determined. We will also attempt to determine whether workers at wastewater spray application sites develop infections by checking for increases of antibodies in their blood stream.

Future Health Effects Research

The future program on health effects of wastewater reuse must necessarily address potable reuse, land application, aquaculture, and industrial recycle at food processing plants. Major highlights include participation in the two large reuse demonstration projects on direct reuse at Denver and land application at Lubbock, Texas. In these and other activities, we will be assessing the health significance of contaminants in the treated wastewaters, such as synthetic organic chemicals and microbiological agents.

The Office of Research and Development is committed to a continuing program of about $1 million per year on the health effects of potable reuse, about the same for health effects of land application, and somewhat less on the effects of aquaculture and industrial recycle. The balance among these areas will shift as new problems are identified. Progress is now being achieved at a pace so that by 1984 we expect to be able to recommend criteria in each of the reuse categories, although future refinements will undoubtedly be required.

SUMMARY

I hope that this overview has given you an impression of the many wastewater reuse research activities of the Office of Research and Development. I would like to say in closing that this is an important area where policy development must go hand-in-hand with research results. As a national priority, it is important that we begin to make increased reuse of an increasingly dearer resource--water--but at the same time we must make sure that community health is not threatened by the contaminants we add to water as we use it. It's critically important that we have the best ideas around brought to the attention of our researchers in this area. After all, we are trying to design and make the water we'll be drinking or using tomorrow.

Influence of the Clean Water Act on Wastewater Reuse Planning

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The Clean Water Act of 1977 requires grant applicants to analyze innovative and alternative technologies for use in wastewater treatment works after September 30, 1978. This requirement of the Clean Water Act and the legislative history of the Act makes it clear that the emphasis on innovative and alternative technologies is intended to achieve increased wastewater reuse and recycling of nutrients. In the words of the Congressional Conference Committee report on the Clean Water Act, EPA "...has been provided all of the legislative tools to require the utilization of such innovative and alternative wastewater treatment processes and techniques." These innovative and alternative technologies emphasizing nutrient recycling, wastewater reuse in agriculture and industry, and energy recovery are to be given preference over conventional wastewater technologies in the EPA program to abate water pollution.

This emphasis on implementation of innovative and alternative technologies will be implemented through provisions of the Clean Water Act which provide incentives and requirements for use of the innovative and alternative technologies in the EPA Construction Grants Program. This paper will discuss the projected influence of these incentives and requirements on the future of wastewater reuse planning and implementation. The factors to be covered include: (1) financial incentives to stimulate more use; (2) requirements to spend a specific part of funds in fiscal years 1979, 1980, and 1981; (3) cost-effective allowances; and (4) new areas of eligibility. These factors will be covered from the perspective of the new law, the EPA promulgation of construction grant regulations, and the EPA issuance of program guidance for implementing the law and the new revisions to construction grant regulations.

PROVISIONS OF U.S. FEDERAL LEGISLATION

Early Federal legislation for water pollution control in the United States had no provisions to encourage reuse or recycling of wastewaters as a conservation practice. The Federal Water Pollution Control Act of 1956 instituted a grants program which actually contained prohibitions and omissions which discouraged development and use of many recycling or reuse alternatives.

The Federal Water Pollution Control Act Amendments of 1972 was the first Federal legislation to contain provisions which encouraged recycle and reuse concepts. The encouragement offered in the 1972 Act was reiterated in the Clean Water Act of 1977 and was given the added impetus of many financial incentives that encompass wastewater reuse.

The Federal Water Pollution Control Act Amendments of 1972 mandated a sweeping Federal/state/local government program to reduce, prevent and eliminate water pollution. This Act contained several provisions directly encouraging reuse concepts. These included: (1) a mandate for the Administrator of EPA to encourage waste management alternatives that would produce revenues from recycling sewage pollutants for production of agriculture, silviculture, or aquaculture products; (2) a provision that grants made from funds authorized for any fiscal year beginning after June 30, 1974, include consideration of alternative technologies and the works proposed for grant assistance provides for best technology adaptable to recycling or elimination of pollutant discharge; and (3) definition of the land that will be an integral part of the treatment process as an allowable cost while retaining land for construction of conventional plants as a non-allowable cost. The message of this Act was straightforward. Planners should give serious consideration to alternatives which combined effective wastewater management with reuse of the wastewater and nutrients. This encouragement of reuse alternatives stimulated more intense discussion between proponents and opponents while having a moderate influence on the actual adoption of reuse and recycling technologies. The moderate influence on actual adoption was a major consideration for the Congress as they formulated the Clean Water Act of 1977.

The Clean Water Act enacted into law on December 27, 1977, did more than carry a straightforward message that water reuse and nutrient recycling deserved serious consideration as a viable waste management alternative. This Act provides many financial incentives for innovative and alternative (I/A) approaches to waste management and specifically designates many water reuse and nutrient recycle approaches as innovative or alternative technology. Among these incentives for I/A projects are the following: (1) the Federal share of a construction grant may be increased from 75% to 85%; (2) a requirement to spend 2% of allocated funds on increasing the Federal share from 75% to 85% in fiscal years 1979 and 1980 (in 1981 this set-aside increases to 3%); (3) the Federal government may participate with full construction grant funding in projects which are up to 15% more costly than the most cost-effective of the conventional alternatives; and (4) projects which fail to meet design criteria may be eligible for 100% Federal grants for modification or replacement. The Congress has supplemented the intent of the 1972 Act to redirect waste management in the US toward reclamation and reuse of wastewater with emphasis on nutrient recycle. These financial incentives underscore the intent of the Congress to force utilization of reuse as opposed to treatment and discharge.

ELEMENTS OF THE US EPA PROGRAM

Most of the identifiable pieces which collectively can be considered as the "Federal guidelines for the reuse of wastewater" are linked in some way to the EPA Construction Grants Program. Section 201 of the Clean Water Act, which authorizes EPA to make grants to municipalities for the construction of wastewater treatment facilities, also requires that grant applicants evaluate "alternative waste management techniques...[which] provide for the application of best practicable waste treatment technology...." Section 201 further specifies that best practicable waste treatment technology (BPWTT) includes "reclaiming and recycling of water and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution...." "Alternative Waste Management Techniques for Best Practicable Waste Treatment" was published by EPA pursuant to Section 304 of the Clean Water Act. Contained in this document are criteria for systems in three categories: treatment and discharge to navigable waters; land application and utilization practices; and wastewater reuse.

It is true that construction grant requirements are directly applicable only to the planning, design and construction of facilities which receive grant funding. Furthermore, the coverage of the rules and regulations under which the Construction Grants Program operates does not extend to the long-term operation of completed facilities, whether these facilities were assisted with grant funds or not. However, because of the magnitude of the Construction Grants Program (i.e., eventual expenditures likely to exceed $50 billion and greater than 12,000 projects), its impact on municipal wastewater treatment practices in this country obviously is considerable. Consequently, even though the Construction Grants Program elements listed above are not regulatory in the formal sense of the word, their impact is often comparable to that of regulations. Where state regulations or guidelines do not exist to control a particular practice, applicable construction grant guidelines have in some instances been adapted to fill this void. In other cases, existing state guidelines have been revised as necessary and appropriate in recognition of Federal requirements.

Best Practicable Waste Treatment Technology

The Best Practicable Waste Treatment Technology (BPWTT) criteria published by EPA in October 1975 contain requirements which for all intents and purposes have the impact of Federal regulations.

Municipal wastewater treatment plants are required by law (PL 92-500) to provide for the application of BPWTT by July 1, 1983. The principal reuse and recycle systems available for implementation include land treatment technologies and industrial reuse. A major objective of BPWTT criteria for all reuse and recycle systems is to protect surface and groundwaters for other uses. The criteria for protection of groundwater for land treatment systems which reuse wastewater while recycling nutrients describe three cases as follows:

CASE I: The groundwater can potentially be used for drinking water supply. In this case the groundwater resulting from the land application of wastewater, including the affected native groundwater, must meet the maximum contaminant levels for inorganic and organic chemicals specified in the National Interim Primary Drinking Water Regulations.

CASE II: The groundwater is presently being used for drinking water supply. In this case, the groundwater must meet the maximum microbiological contaminant levels specified in the National Interim Primary Drinking Water Regulations as well as the levels for chemicals specified in Case I.

CASE III: The groundwater has uses other than drinking water supply. In this case groundwater criteria are to be developed by the EPA Regional Administrator based on the present or potential use of the groundwater.

The National Interim Primary Drinking Water Standards for inorganic and organic chemicals and microbiological contaminants presently include limits on arsenic, barium, cadmium, chromium, lead, mercury, nitrate, selenium, silver, fluoride, endrin, lindane, methoxychlor, toxaphene, chlorophenoxys (2,4-D and 2,4,5-TP Silvex) and coliform bacteria. Where a land treatment system results in a surface discharge (i.e., either effluent collected through underdrains or runoff from an overland flow system), the wastewater must meet the BPWTT standards for treatment and discharge. The minimum level of treatment required for municipal systems which treat and discharge to surface waters is secondary treatment as defined by EPA in terms of five-day BOD, suspended solids and pH. It is important to note that in any case, the point at which the wastewater is measured for compliance with the Federal BPWTT criteria is when it leaves the land treatment system (i.e., becomes part of the permanent groundwater or is surface discharged) and not at the point of application to the land.

Innovative and Alternative Technology

The Clean Water Act of 1977 clearly established the intent of Congress to encourage the use of innovative and alternative technology in the Environmental Protection Agency's multi-billion dollar Construction Grant Program for control of pollution from municipal treatment facilities.

The legislation contains specific sections that refer to innovative and alternative technology. The Environmental Protection Agency, in fulfilling its mandate under the CWA of 1977, has published final regulations pertaining to innovative and alternative technology. Extensive reviews of the legislative history of the Act along with consideration of the voluminous public comment and results of public hearings have led to the formulation of the innovative and alternative technology guidelines identified as Appendix E of the final regulations.

The underlying concept of the innovative and alternative guidelines is the provision of a basic monetary incentive, i.e., a grant increase from 75% to 85% for the design and implementation of municipal treatment technology that represents an advancement of the current state-of-the-art technology. Emphasis is placed on use of technologies directed to meeting the specific national goals of (a) greater recycling and reuse of water, nutrients, and natural resources (b) increased energy recovery and conservation (c) improved cost-effectiveness in meeting specific water quality goals, and (d) improved toxics management.

The legislation, guidelines, and Agency policy have been structured to provide additional incentives to both the public and private segments of the municipal construction industry most directly responsible for implementation of improved wastewater management systems. Specific efforts have been made to encourage the use of innovative concepts in the planning and design of municipal treatment facilities by providing indemnification of risk through the provision of 100% grants for modification of facilities which fail.

A major emphasis of innovative systems under the Clean Water Act of 1977 is the greater attention placed on multi-objective planning, intermedia impact considerations, and total systems design. Satisfaction of these objectives require a more systematic screening and evaluation of alternatives than has been generally employed in the past. More important, however, is the much greater effort needed in concept development and the formulation of innovative alternatives.

Past experience with the planning of wastewater management in the US has indicated a strong tendency for contemporary designers to consider a narrow range of alternatives, both with respect to liquid processing technology and also for residual treatment and disposal. Innovative design concepts should include a broad range of reuse, beneficial recycling, and energy conservation and recovery opportunities, as well as the common treatment and discharge technologies. There are many recycling, reclamation, and energy recovery opportunities that might be incorporated into an innovative concept of wastewater management. These are described and discussed in the Agency manual on innovative and alternative technology assessment.

Conceptually, innovative designs may embody a number of recycle/reclamation or reuse opportunities depending on the particular site variables and design objectives. Maximum consideration should be given to the identification of all potential conceptual approaches early in the planning process, especially those system designs incorporating alternative technologies that exhibit significant recycle, reclamation, energy recovery, or revenue generating potential.

Land treatment of municipal wastewaters has been identified as a leading example of an alternative technology which emphasizes wastewater reuse coupled with recycle of nutrients for beneficial crop production. The USEPA has issued specific policy and construction grants guidance for this recycle and reuse technology. This specific guidance on a popular alternative technology will be discussed in more detail.

EPA Policy Statement on Land Treatment of Municipal Wastewater

On October 3, 1977, the Administrator of the Environmental Protection Agency issued a policy statement on land treatment of municipal wastewater. The policy statement highlighted the Agency's intent to "press vigorously for publicly owned treatment works to utilize land treatment processes to reclaim and recycle municipal wastewater." It also required that construction grant applicants who do not select methods that encourage water conservation, wastewater reclamation and reuse must provide a complete justification for the rejection of land treatment.

With respect to "guidelines" for land treatment systems, the October 3, 1977, statement emphasized the importance of ensuring that Federal, state and local requirements and regulations are imposed at proper points in the treatment system. To this end, the statement indicated that "Whenever states insist upon placing unnecessarily stringent preapplication treatment requirements upon land treatment, such as requiring EPA secondary effluent quality in all cases prior to application on the land, the unnecessary wastewater treatment facilities will not be funded by EPA." This is not to say that secondary treatment or an even higher level of treatment may not be necessary for some land application projects. The intent is to cause arbitrary preapplication treatment requirements, such as a minimum of secondary treatment or better in all cases, to be revised to reflect a level of preapplication treatment appropriate for the given situation. Just as secondary treatment may be appropriate in some instances, the equivalent of primary treatment or even raw wastewater may be sufficient in others. More discussion of preapplication treatment requirements is presented in the next section of this paper.

Program Requirements Memorandum for Evaluation of Land Treatment Alternatives

On November 15, 1973, the US EPA issued Program Requirements Memorandum (PRM) No. 79-3 titled "Revision of Agency Guidance for Evaluation of Land Treatment Alternatives." PRM's are issued by the Agency to set forth policy for implementation of the Construction Grants Program. This particular PRM was developed to provide guidance in support of the October 1977 policy statement issued by the Administrator of EPA.

Again, while a guidance document such as this PRM is specifically developed for implementation of the EPA Construction Grants Program, it does constitute Agency policy. In this way it can be interpreted as having the effect of Federal guidelines, particularly because PRM's and other similar issuances are widely circulated for review and comment prior to publication in final form.

The PRM establishes the US EPA "Process Design Manual for Land Treatment of Municipal Wastewater" as the principal reference fo technical information upon which review of construction grant projects involving land treatment will be based. The PRM also cites three planning and design factors which have historically limited the use of land treatment in this country. These factors are: (1) overly conservative and, consequently, costly design of slow rate (water reuse and nutrient recycle) systems; (2) failure to consider rapid infiltration as a proven water reclamation alternative; and (3) requirements of substantially higher and more costly level of preapplication treatment than is needed to protect health and ensure design performance.

The PRM also provides more specific guidance on four items related to the design of land treatment systems. These four design-related factors are site selection, loading rates and land area, preapplication treatment, and environmental effects. Much of the information pertinent to these factors is included in the PRM by reference to other documents such as the Design Manual and the BPWTT publication.

An important point to re-emphasize is EPA's approach to the issuance of design criteria such as these. The Agency recognizes that no single value or even one set of values can be realistically applied to all locations considering the variability across the country in climate, geology, treatment needs and other factors affecting the design of land treatment systems to recycle nutrients or reuse wastewaters. For this reason the EPA guidelines are varied to suit a number of possible situations and include ranges of values wherever possible. For example, the range of application rates indicated in the PRM varies from 0.6-6 M/yr for slow rate systems to 6-170 M/yr for rapid infiltration systems.

This concept of flexibility is particularly important with respect to EPA's position on preapplication treatment requirements. The EPA statements on preapplication treatment have apparently been misconstrued by some who have interpreted them as indicating that the Agency will not support any project which requires secondary treatment prior to application to the land. This is not the case. What the Agency is saying is that the level of preapplication treatment must be suited to the particular situation. As previously noted, in some cases primary treated or even raw sewage may be acceptable for application to the land, while in other instances treatment beyond that provided by secondary may be necessary. Clearly an arbitrary requirement that all wastewater has to receive secondary treatment prior to land application is not consistent with the Agency's approach. The guidance on preapplication treatment included in the PRM ranges from simple screening or comminution for overland flow in isolated areas with no public access to extensive BOD and suspended solids control with disinfection for reuse systems in public access areas such as parks and golf courses.

SUMMARY

This paper presents an overview of guidelines applicable to reuse of municipal wastewaters as mandated by the Clean Water Act and the US EPA extention of this mandate into Federal guidance for management of the US EPA Construction Grants Program. Reuse of municipal wastewater and recycle of the nutrients it contains through the innovative/alternative technology thrust of the US EPA Construction Grants Program is only one aspect of conserving water supplies through reuse. However, the magnitude of the program (i.e., eventual expenditures likely to exceed 50 billion US dollars involving over 12,000 projects) will produce an obvious impact on technology development for reuse and recycling of municipal wastewater throughout the world.

Because it would not be possible to describe in detail the individual features of guidelines in a paper of this nature, the approach taken was to outline the major elements which provide the framework for the US government criteria applied to reuse and recycle systems. More specific information is contained in the documents and publications highlighted in the paper. Copies of "Alternative Waste Management Techniques for Best Practicable Waste Treatment" (EPA 430/9-75-013), the Administrator's Policy Statement of October 3, 1977, and the Program Requirements Memorandum on evaluation of land treatment alternatives and the "Innovative and Alternative Technology Assessment Manual" (EPA 430/9-78-009) can be obtained by writing to Chief, Municipal Technology Branch (WH-547), EPA, Washington, D.C. 20460. The "Process Design Manual for Land Treatment of Municipal Wastewater" (EPA 625/1-77-008) can be obtained from the Environmental Research Information Center, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

APPLIED SCIENCE AND ITS ROLE IN ADDRESSING PROBLEMS RELATING TO RENOVATION AND REUSE OF WATER

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Listening to Colonel Reuter's cogent explanation of the obstacles to faster progress in the area of water reuse gives me a strong sense of history repeating itself. Back in the early 70's, you may remember, a few prophets were voicing pessimism about the prospects for action on another problem. The problem was similar to water reuse, in a number of respects. It, too, involved shortages and the need to conserve a scarce resource. It, too, involved possible Draconian consequences--but somehow, no one believed the day would come when we'd actually have to face the problem.

By now you know what I'm talking about: energy resources and conservation. Some say we're still not doing enough about it, but hardly a day goes by when energy isn't on the front pages, or high on the agenda of key officials, all the way up to the President himself.

I recall this history of how energy conservation became a high national priority because the National Science Foundation had a role in helping make it so. We were among the first government agencies to establish research programs on energy conservation and non-nuclear alternatives to fossil fuels. My point is that once energy conservation caught the nation's attention, earlier research was important in demonstrating the range of technologies that could be developed to address the problem. The results of our research helped convince policymakers that a program of action was feasible. Like Colonel Reuter, I sometimes fear that a similar process of near crisis will be necessary before society is ready to make significant investments in water reuse.

As you know, through the efforts of many people and organizations, we have made significant progress in identifying technologies for water resue and in developing methods for applying those technologies. But there are still large gaps in our knowledge about water supply, water consumption and water quality; and the effects of both availability and quality on man and other natural resources. We also need to bring the knowledge we have to the attention of policymakers and water managers in a form that leads to action. At the National Science Foundation we are investigating the problems of water supply, use and reuse through research that spans the spectrum from basic to applied and to proof of concept of the most promising technologies.

Those of you in the research community are most familiar with the Foundation's role in fostering basic science. That is, indeed, a primary mission. But we have also had authority to fund applied research since 1968, and over the past decade we have evolved a goal for applied research that has made water reuse an ideal candidate for our support. That goal, as recently defined by the Foundation's policymaking Board, is to enhance the returns from basic research by encouraging

> development in those areas of science with exceptional promise for contributing to the resolution of significant problems. . . .

The problems of water and water reuse clearly fit into this goal. But before describing the work we do in my part of the Foundation--the Applied Science and Research Applications Directorate--I want to touch briefly on the importance of continuing our search for basic knowledge. No one who has looked at the phenomenon of water can say that we know enough about it. Take the issue of groundwater supply. According to a recent House Science and Technology Subcommittee report, our withdrawals of groundwater have more than doubled over the past 25 years and are increasing at the rate of four percent annually. In many areas, these withdrawals cause severe problems, including increased drilling and pumping costs due to declining water levels; conflicts between urban and agricultural use; and contamination of the aquifers both by salt and by disposal of pollutants on the surface. Some areas may eventually run out of groundwater.

When you think about it, our ability to manage water depends on developing much more precise knowledge of a number of phenomena, such as long-range weather and rainfall patterns, rate of percolation in different types of soils and geologic structures, movement of contaminants through various soils, the boundaries and natural discharge rates of aquifers, as well as ways to manage the use and reuse of water.

At the Foundation, a number of our research directorates are addressing aspects of all of these elements. It is vital that we continue to build our basic knowledge in all these areas. Meanwhile, we must do the best we can with the knowledge we have today.

That brings me to the Foundation's efforts concerning the application of water research results. One of my colleagues, Ed Bryan, will be describing some of these efforts in greater detail here tomorrow. All I will do is highlight a few projects that illustrate the range of work we have done, our current priorities, and where we might go in the future.

Some of our most successful efforts have been in our Community Water Management and Chemical Threats to Man programs. In the former area, for instance, we take pride that our work on wastewater handling and sludge disinfection has led to tests and demonstrations that are now being supported by Federal mission agencies. We've also been concerned with water allocation problems. Surveys we have supported have demonstrated that voluntary water restrictions are significantly less successful than mandatory ones and that citizens generally fail to meet voluntary standards although they tend to exceed conservation targets when the controls are not voluntary. We have sponsored studies designed to provide guidelines for overall drought management strategies in urban areas.

In our Chemical Threats to Man program we have, over the past three years, developed and refined techniques for accurately monitoring and tracing organic and inorganic substances in water and elsewhere in the environment. We have also supported research on the processes that occur when organic and inorganic compounds interact with water; and on the rate of biological degradation of organic chemicals and the effects of ultraviolet light and ozone in decomposing organic materials.

Both the Water Management and Chemical Threats programs have achieved significant milestones and a stage where we think it appropriate to turn this research over to the mission agencies. We are, therefore, phasing them out this year. Meanwhile, our basic research directorates continue to support projects that increase our understanding of the nature and behavior of pollutants in the environment. And I can assure you that my directorate will continue to examine the need for other targeted water resource and management programs.

For the future, we see the need for long-range research that can provide information useful to water resource managers. Much of it is going to have to be interdisciplinary if it is to have any payoff because--as Colonel Reuter noted--many obstacles in this field are behavioral, not technical. Thus, we need to do more than develop ways to reuse water. We need to learn more about the economics of water reuse and understand public acceptance of reuse systems. We also need a better knowledge of how to balance competing demands on water supply.

At this point, some of you may be asking whether any of the knowledge the Foundation developed has actually been put to work solving the problems of water reuse. Frequently we insist that our investigators bring in users or a user advisory panel to help design the research, monitor the results, or disseminate the findings. We do this because we think it's the best way to ensure some payoff to society.

And where a specific application or use appears technically feasible, and holds promise of substantial benefits from commercialization, we carry the idea as far as proof of concept in an actual operating environment. A good illustration of this is a highly promising project we are supporting in New Jersey. It involves the use of warm water discharge from a power plant to grow fish for food. If we can prove that this reuse of water is commercially viable, it will reduce "thermal" pollution by diverting some of the warm wastewater to aquaculture ponds. This will help utilities meet the cost of complying with water quality standards mandated by Congress. They can either "rent" their warm water resource to aquafood companies or produce and sell the fish themselves.

This water reuse concept, if successful, will also conserve energy. Utilities will be utilizing an otherwise wasted energy source to grow fish close to market. These are fish that otherwise would have to be caught and transported long distances in boats and trucks that use fossil fuels.

Some indication of the seriousness with which the industry and others take the concept is their direct involvement in the project.

First, the utility, the Public Service Electric and Gas Company, is not only managing the project and providing the aquaculture plant, but also is funding a significant portion of the project costs. A commercial producer is providing consultation on aquaculture and marketing. During the past year, the New Jersey State government was briefed by the project team on the potential for development of an aquaculture industry. The New Jersey Senate has already passed a Fisheries Development Bill. The potential for developing an aquaculture industry nationally is also great. According to one estimate, if only 10 percent of the fossil-fuel power stations in the United

States used their heated effluents in a system like the one in New Jersey, we could produce 500 million pounds of fish a year, or about half of our total annual fish consumption.

I have two points to emphasize on this project. First, we at the Foundation are not satisfied just to add to the nation's storehouse of scientific and technological knowledge. We are also interested in directing research to areas that have promising payoffs for society. Second, we work closely with--and indeed depend on--you who are on the operating line. We hope you will come to us with problems that you think research can help solve and cooperate with us when we think we have an idea worth trying out.

NSF has only a small fraction of the R&D funds in the Federal budget, and my directorate represents a small fraction of the total Foundation budget. But we are always looking for promising areas of investigation, and--as I indicated before--we frequently look for non-academic partners in the research we support. In my directorate we have an "open window" for applied research proposals. Here, investigators can define the problems they want to work on. I should point out that the flow of these proposals--both the ones we fund and those that we don't--help determine future directions for our applied research.

Once again, let me assure you of the Foundation's continuing interest in the problems of water reuse and our desire to work closely with and support the efforts of the mission agencies in meeting the problems of water supply and quality.

If you have any questions, I would be happy to take them at this time. Thank you.

The National Science Foundation's Role in Support of Research Relating to Reclamation and Reuse of Wastewater

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Introduction

Since its establishment in 1950 as an independent agency of the Executive Branch of the Federal government, the National Science Foundation (NSF) has provided support for research which has contributed toward a better understanding of scientific principles including those related to global cycling of water, the ultimate and most comprehensive system for reclamation and reuse of wastewater on earth. Congressional action in 1968 that authorized NSF to support applied research, initiated programs the content of which related to management of water, reclamation and reuse of wastewater, and associated problems and alternatives to meet societal needs for sufficient water of acceptable quality. Most of the support that NSF has provided for water and wastewater-related issues have been channeled through programs in its "environmentally focussed" administrative units.

Basic Research

Basic research relating to water is broadly supported by the National Science Foundation through programs in:

- Mathematical, Physical Sciences and Engineering
- Astronomical, Atmospheric, Earth and Ocean Sciences
- The U.S. Antarctic Programs
- Applied Science and Research Applications
- Scientific, Technological and International Affairs

Presented at the Water Reuse Symposium on March 27, 1979 in Washington, D.C. The opinions expressed are those of the author and do not reflect an official position of the National Science Foundation or of any other Federal Agency.

The Division of Engineering, through its program in Water Resources, Urban and Environmental Engineering is currently supporting basic research on the following water-related topics:

- Erosion and transport of sediments.
- Water and wastewater treatment.
- Diffusion, dispersion and biological interactions of pollutants.
- Hydrology and water resources.
- Flow in underground aquifers

A workshop, organized and conducted by the Association of Environmental Engineering Professors was held in December of 1977. It addressed fundamental research needs for water and wastewater treatment. Proceedings of the workshop, which are currently being utilized to help guide formulation of that program, are available from the National Science Foundation or from the National Technical Information Service (1).

Applied Environmental Research

The applied research programs which support water and wastewater-related research were located in the Division of Environmental Systems and Resources. This unit was renamed the Division of Advanced Environmental Research and Technology in 1975. Early in 1978, as part of a major reorganization of the applied research functions within NSF, the shift of the program in Weather Modification to the basic research directorate was completed and water and wastewater-related components of the programs in Regional Environmental Management as well as the program in Chemical Threats to Man and the Environment were placed in a new Division of Problem-Focussed Research Applications (PFRA).

The common objective of all programs that were assigned to the new, problem-focussed administrative unit was to focus scientific and technological capabilities on selected societal problems where NSF could make a unique contribution toward their timely and practical solution. At any point in time, it was expected that the PFRA unit would be addressing four to six problem areas.

Descriptions of awards that were made by NSF in support of applied environmental and related objectives are contained in Summaries of Awards (2)(3)(4)(5)(6)(7)(8). The program titles and the fiscal years during which awards were made in support of the program objectives are contained in Table 1. The sequence of programs that began with Regional Environmental Systems and ended with Community Water Management consistently dealt with aspects of wastewater reclamation and reuse of water.

TABLE I

Summary of NSF Applied Environmental Programs with Substantial Water Resources, Wastewater and Reuse Components

Program Name	Fiscal Years Active
Regional Environmental Systems	1971 - 1975
Regional Environmental Management	1976 - 1978
Community Water Management	1978 - 1979
Environmental Aspects of Trace Contaminants	1971 - 1975
Environmental Effects of Energy	1975
Chemical Threats to Man and the Environment	1976 - 1979
Weather Modification	1971 - 1977

Community Water Management

The Community Water Management program traced its origin to elements of the former program that dealt with water-related issues of land use, urban hydrology, residuals and environmental risk management. Its goal was to support applied research focussed on management of water at the community level to achieve and maintain acceptable levels of health, safety and environmental quality at reasonable cost. The program was designed to meet that goal by supporting research that identified, assessed and evaluated innovative concepts for management of threats to community water leading to design and evaluation of potential solutions to problems associated with use and reuse of water and related issues. The program strategy was to concentrate on a few issues that were judged to be important, potentially responsive to scientific inquiry and with regard to which NSF could make unique contributions toward their resolution. Research on each issue selected was planned to end with a Proof-of-Concept Experiment after which and as determined to be consistent with its results, development would be assumed by a mission agency or the private sector. Determination that the concept evaluated was not feasible was a possible outcome of this experiment as a consequence of the Foundation's assumption or responsibility for support of "high-risk" research.

The Proof-of-Concept Experiment may be conceived as the one in which the concept meets the "real world" after which encounter a decision is reached as to its suitability for development. This in turn is the process by which the credibility of the concept is measured... that is, the difference between what research promised and what people can deliver.

The issues that its precursor program had addressed and which were retained as initial ones in Community Water Management were:

- Sludges from treatment of wastewaters.
- Effluents from secondary treatment processes.
- Diffuse/non-point sources of pollution
- Water shortages.

Continued support of research was planned to evaluate innovative concepts that were directly and peripherally related to these issues because of their basic relationship to the more directed and problem-focussed research. Conferences and workshops were also planned to assist in definition of problems and in assessment of research needs. Conferences and workshops held to assess research needs and related to each of the issues selected for initial focus included the following:

- Drought Research Needs, A conference held at Colorado State University in December 1977 (9).

- Water Quality and Health Significance of Bacterial Indicators of Pollution, A conference held at Drexel University in April 1978 (10).

- Health and Legal Implications of Sludge Management, A conference held at Harvard University in December 1978 (11).

- Efficacy of Intensive Aquatic Plant Harvesting for Management of Nutrients from Diffuse, Non-Point Sources, A conference held at the University of Wisconsin in February 1979 (12).

In addition, reports for NSF were prepared by several consultants in response to requests from program staff. These documents were planned to be utilized in redirection of the program toward new and emerging issues of significance and importance (13)(14)(15)(16).

Proof of Concept Experiments

Two Proof-of-Concept experiments (POCE) are currently underway and a third one was planned for initiation during 1979. Those in progress are as follows:

- "Utilization of Waste Heat From Power Plants in Aquaculture", Public Service Electric and Gas Company, Newark, New Jersey. The experiment is located at the Mercer Generating Station in Trenton, New Jersey and is being conducted jointly by personnel from Public Service Electric and Gas Company, Rutgers University and Trenton State College (17).

- "Wetland Utilization for Management of Community Wastewater", University of Michigan, Ann Arbor. The wetland being evaluated in this full-scale experiment is located near Houghton Lake in the state of Michigan (18).

The experiment in progress at Trenton, New Jersey has as its objective the determination of the technical and economic feasibility of utilizing the waste heat contained in cooling water for culturing edible aquatic animals of commercial value. Earlier research initiated with support from NSF had shown that a concept of alternating the culture of warm and cold-water species was potentially more likely of commercial success than a single-species concept. This research pointed toward the possibility of constructive utilization of cooling water to accelerate growth, reduce pollutional impact from thermal discharges to receiving waters and provide economic returns to offset costs of thermal pollution abatement by production of marketable products of relatively high value. Species that have been or are being evaluated include rainbow trout, freshwater shrimp, striped bass, channel catfish and American eels. Long Island Oyster Farms, Inc. and the New Jersey Department of Agriculture are assisting in conduct of this experiment.

The experiment underway in Michigan has as its objective the assessment of the feasibility of using natural wetlands to achieve the treatment goals of tertiary or advanced wastewater treatment concepts. Background research leading to this Proof-of-Concept Experiment was initiated with NSF support of basic wetland ecosystem modelling studies at the University of Michigan in 1972-73. This two-year study led to an additional award for support of limited model-verification work which in turn led to pilot scale studies. Confidence gained in the concept as a result of this research led to acceptance of the concept for full-scale implementation by the State of Michigan and approval by the U.S. Environmental Protection Agency for use of construction grant funds in construction of the wetland application system. The National Science Foundation is providing support for the research component of this experiment by grants to the University of Michigan.

The consulting engineering firm of Williams and Works, Inc. of Grand Rapids, Michigan, designers of the Houghton Lake wastewater treatment facilities, is also evaluating with support from NSF a "synthetic" wetland at Vermontville, Michigan to determine its performance capability in comparison with alternative land application concepts for meeting advanced wastewater treatment standards (19). The wetland research in progress at Houghton Lake and Vermontville in Michigan is being coordinated with research by investigators at the University of Florida (20), the Florida State Department of Health (21) and Boyle Engineering Corporation (22) to determine the feasibility of utilizing cypress domes and strands for management of municipal wastewater. The research sites in Florida include cypress dome wetlands in Alachua County near Gainesville and a cypress strand wetland near Jasper.

A third Proof-of-Concept Experiment was planned for initiation during FY 1979 to assess the feasibility of an innovative concept for management of sludges from community wastewater treatment plants. This concept originated from NSF-supported basic studies at the University of Texas in which viruses were shown to be concentrated in wastewater treatment plant sludges where they remained viable.

Continuation of this research was directed toward determining survival and translocation characteristics of viruses in soil and to gain insights into their significance with regard to risk (23). As a potentially responsive measure, support of research at the Massachusetts Institute of Technology (24) led to determination that energized electrons were effective in disinfection of sludges. Finally, evolution of the integrated concept was completed when research by Colorado State University investigators (25) led to the conclusion that liquid sludges could be injected directly into topsoil and the site managed with a high degree of public acceptability.

The possibility of using pipeline-transport of raw sludges which had been disinfected from the point of their origin to the controlled injection site where they would be stabilized after injection into topsoil offers potential cost advantages estimated at $100 per dry ton over conventional sludge management concepts. The degree of disinfection of raw sludges that may be required prior to their injection into soil at a carefully managed site is not presently known. However, it may be presumed that to achieve acceptability of any new concept by authorities responsible for decisions relating to public health, disinfection at least equal to that accomplished by the displaced processes is likely to be required. If this concept proves to be as economical as it seems based upon the background research, adoption by communities responsible for only ten percent of the sludge produced in the United States would result in savings every twenty days equal to the $3 million in grants made by NSF to the seventeen organizations that conducted preparatory and related research. This estimate in cost savings does not include additional, potential benefits such as nutrient recovery by sale of topsoil and/or crops and a credit for elimination of costs associated with additional treatment plant capacity to accommodate return flows associated with dewatering unit processes.

Research recently completed or currently in progress relating to recycling, reclamation and reuse of wastewater that has reached a stage where the design of suitable Proof-of-Concept experiments seems now appropriate includes the following:

- Application of sequencing batch reactors for treatment of water and wastewater (26)(27)(28)(29)(30)(31)(32).
- Multiple water supply approach for management of urban needs (33)(34).

Conclusion

The National Science Foundation's role in supporting research is likely to continue to be concentrated on a search for basic knowledge and interpretation of facts. It seems apparent that research alone, whether basic or applied, can only contribute toward the solution of problems. It needs linkages with the practical world. The search for knowledge and understanding of relationships between cause and effect is a search for both truth and wisdom.

The optimal structure for a National research program addressing water needs will be one that clearly identifies not only the research needs but the way in which those needs will be met. It seems clear that wastewater reclamation and reuse will be essential components of any strategy that realistically addresses our future problems relating to water.

Increasing societal pressure against the relatively fixed amount of water available for use will result in an ever-increasing challenge to find innovative and alternative ways to effectively increase the utility of existing supplies. The potential for enhancement of returns from the National investment in basic research to resolve the complex scientific, engineering, technical, legal, economic and social issues relating to water, its use and reuse is substantial and can only increase with time. The National Science Foundation is likely to continue playing an important role not only in its support of basic research for pursuit of knowledge but in the application of that knowledge in ways that identify, assess and enhance its usefulness in resolving those issues.

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WATER RECLAMATION EFFORTS IN CALIFORNIA

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The importance of an adequate water supply for California's 22 million people, and its agriculture and industry cannot be overemphasized. Due to its steady economic and population growth, California's water demand is continuously increasing. This fact, combined with the uneven distribution of population and surface waters (population in the South and Coastal areas - water in the North) as well as the fluctuation in annual precipitation, necessitates very careful water resources management to assure adequate water supplies for all needs of Californians. Massive water storage and transport projects have helped to offset geographically imbalanced supplies and allowed the State to grow and prosper. During years with normal rainfall, water delivery from state and federal projects is almost taken for granted. The critical nature of California's water supply and its growing shortages can only be appreciated fully during drought periods. More than anything in recent history, the 1976-1977 drought in California focused attention on the need to develop several water resource management alternatives to assure that California's water needs are met at all times. These alternatives include measures to reduce water consumption, water exchanges and transfers, conjunctive use of ground and surface waters, and water reclamation. While the drought underscored the need for water reclamation, reclamation is by no means a water management alternative for drought years only, but should be considered an integral and permanent part of California's water supply. The purpose of this presentation is to describe the role of water reclamation in California and the actions taken to assure that water reclamation will contribute significantly to meet the increasing demand for new water.

NEED FOR WATER RECLAMATION IN CALIFORNIA

In 1972, the annual water demand was 31 million acre-feet (m acre-ft) and shortage was 2.5 m acre-ft. In 1977, the demand was 35.4 m acre-ft and the shortage, because of the drought was a staggering 10.8 m acre-ft. It is estimated that by the year 2000 the demand will be 39.1 m acre-ft with an annual shortage of about 4.3 m acre-ft assuming normal rainfall and that several currently proposed water development projects such as Auburn Dam, Peripheral Canal, and others will be completed. (Figure 1). If these projects are not completed, the annual water supply shortage by the year 2000 will reach 6.6 m acre-ft.

In the past, the continuous and increasing shortages have been met by import from unreliable sources and from groundwater overdraft. Groundwater overdraft has caused land subsidence, depletion of water supplies, increased pumping costs, and salt water intrusion in many areas of the state. Prior to the 1976-77 drought, groundwater was being overdrafted at the rate of about 2 m acre-ft annually. During the drought, an estimated 10,000 new wells were constructed and overdraft increased to over 8 m acre-ft per year (m acre-ft/y). The

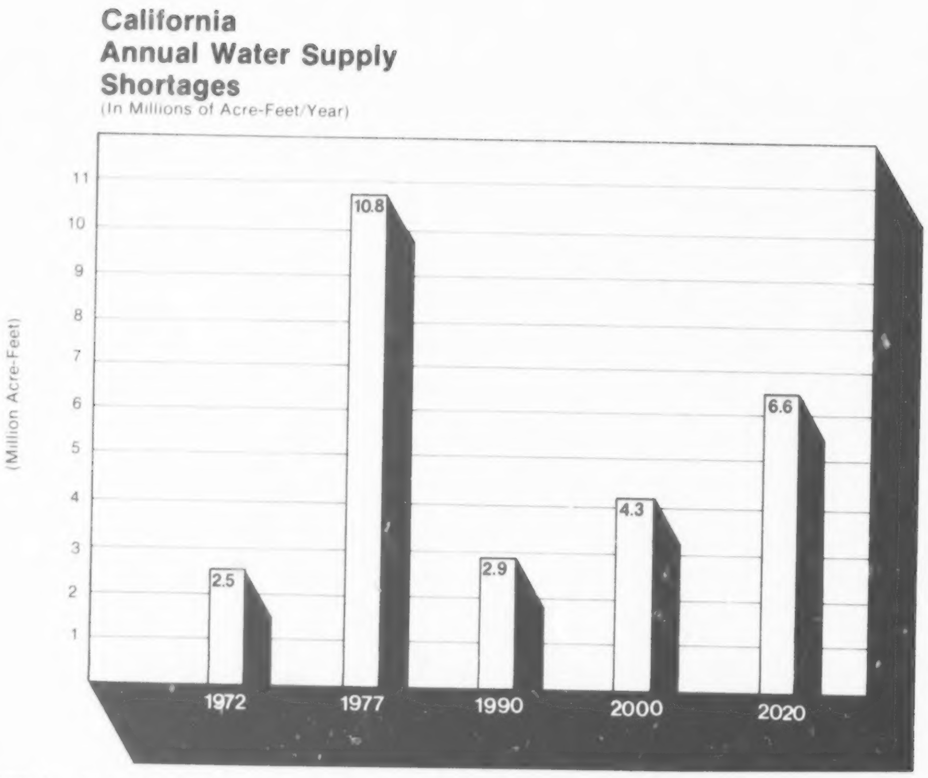

FIGURE 1: PAST AND ANTICIPATED WATER SUPPLY SHORTAGES IN CALIFORNIA (ASSUMING PLANNED WATER DEVELOPMENT IS ON SCHEDULE) - (4)

groundwater basins are vital for California's water resource management; they supply up to 50 percent of the water consumptively used by agriculture and municipalities and it is therefore essential that this trend be halted and overdrafted basins be restored to their natural balance.

Without any action to improve water resources management and development of new supplies, statewide net demands in the year 2000 could exceed dependable supplies by as much as 6.6 m acre-ft/y. In order to prevent such unacceptable conditions, the Department of Water Resources developed a comprehensive water management program to meet the projected water supply demands through the year 2000 (Figure 2). This plan combines several water resource management alternatives including water conservation and alternative water supply development and will result in reduction of California's reliance on groundwater overdraft.

New reclamation is expected to contribute at least 600,000 acre-ft/y. In addition to providing a new and more dependable water supply and saving energy, water reclamation can also result in significant water quality benefits. Pollutants will no longer be discharged to surface waters, salt water intrusion and groundwater overdraft can be reduced or eliminated.

At a time when Southern California is importing large quantities of water from the Colorado River and Northern California, about 93 percent of the area's wastewater is being wasted by discharge to the ocean and therefore lost as a valuable resource. By the year 2000, an estimated 3.2 m acre-ft of treated wastewater will be discharged from California's coastal areas. About 2.6 m acre-ft of which is reclaimable. Reuse of this water could significantly reduce the anticipated annual shortage.

The benefits of water reclamation have been recognized for many years. The State Water Code states that: "It is the intention of the California Legislature that the State undertake all possible steps to encourage development of water reclamation facilities so that reclaimed water be available to help meet the growing water requirements of the State" and directs the State Water Resources Control Board to give added consideration to funding of reclamation projects. In fact, a recent Water Code amendment forbids the use of potable domestic water for landscape irrigation when suitable reclaimed water is available. This legislative mandate to encourage water reclamation demonstrates public recognition of reclamation and its role in helping to meet current and future water needs.

STATUS OF WATER RECLAMATION IN CALIFORNIA

Water reclamation is not a new concept in California. Already in 1918 the State Board of Health adopted the first regulations for use of treated sewage for crop irrigation. Use of reclaimed water has been increasing since then. In 1935, for example, there were 64 reclamation projects - 62 of them producing reclaimed water for irrigation of fiber and fodder crops. In 1978 215,220 acre-ft of wastewater was reused. 69 percent of the wastewater was used for agricultural irrigation, thirteen percent landscape irrigation, twelve percent for groundwater recharge, five percent industrial and one percent for miscellaneous uses. (Table I).

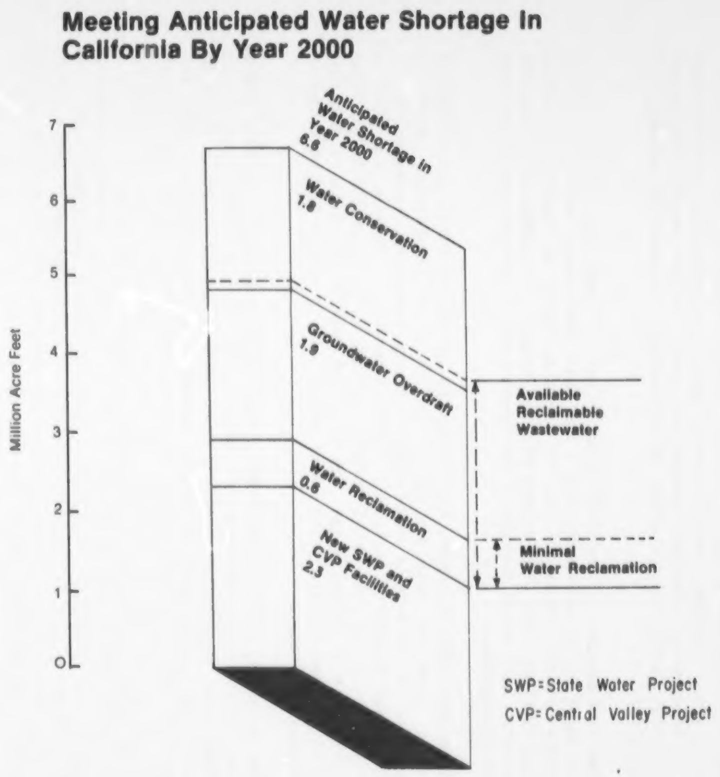

FIGURE 2: MEETING ANTICIPATED WATER SHORTAGE IN CALIFORNIA BY YEAR 2000 - (5)

TABLE I
PRESENT WATER REUSE IN CALIFORNIA

Type of Use	Number of Operations	Acre Feet Per Year	Percent of Volume
Agriculture	232	147,920	69
Landscape Irrigation	104	28,700	13
Groundwater Recharge	5	26,060	12
Industry	22	10,480	5
Recreational Impoundments	13	880	<1
Other	3	1,180	<1
Total	379	215,220	100

Although, the majority of water reuse projects in California involves irrigation, other types of reuse are also represented and their number is steadily increasing. An outstanding example of an earlier industrial water reuse application is the Kaiser Steel Corporation's Fontana plant where about 750,000 gallons of both domestic and process wastewater are reclaimed and reused daily. This project was the first industrial reuse project constructed in California. Water consumption, per ton of steel, is only about three percent of industry's average. Significant groundwater recharge operations in California include Montebello Forebay recharge by the Los Angeles County Sanitary District, where about 30 million gallons per day (mgd) have been recharged since 1962 and the Orange County Water District's Water Factory 21 where fifteen mgd are injected into aquifers to form a salt water intrusion barrier. Other uses of reclaimed water involve recreational or landscape impoundments and instream flow augmentation. Oil field repressurization is being evaluated as a possible reuse of reclaimed water.

CONSTRAINTS TO WATER RECLAMATION

While the need to expand the use of reclaimed water in California is clearly evident, there are often major constraints which must be addressed and resolved before reuse projects can be implemented. These constraints include economics, public health, water quality, institutional and legal issues, and public acceptance.

Economics. Economic constraints to increased water reuse include the following:

- Relative low cost of most of the present freshwater supplies. This is due primarily to the supplies coming from the most easily developed sources.
- The subsidized imported water, particularly in the case of the federal Central Valley Project. This reflects low power costs based on long term power supply contracts and ad valorem tax subsidies.
- Additional costs incurred when using reclaimed water instead of freshwater. These costs are due to necessary treatment beyond what is required for pollution control or because of need for stricter controls of reuse operations.

It is clear that any future development of freshwater supplies will involve much less favorable conditions, and this will be reflected in substantially higher costs. For example, in the Southern California service area of the State Water Project, the price of water will increase because of the expiration of the long term power contracts. The new contracts will reflect actual power costs, which are over ten times higher than present rates.

When the actual cost of reclaimed water is compared with the cost of freshwater development, the total cost of reclaimed water is frequently less than the costs of future water development.

The recently completed water supply cost analysis for Orange County Water District (see Table II) illustrates how reclamation energy needs and actual overall costs compare favorably with energy needs and costs of imported water in this area. Table II indicates that the present cost of reclaimed water is high in comparison with imported water. The actual cost, reflecting the present power costs and without the ad valorem tax subsidy, is lower than the cost of imported water supplies. As far as energy consumption is concerned, the Colorado River supply is the least energy consuming alternative; however, its quality is marginal and delivery of this water to California will be drastically reduced by the mid 1980's due to the completion of the Central Arizona Project.

TABLE II
COST OF FUTURE WATER SUPPLY ALTERNATIVES FOR
ORANGE COUNTY WATER DISTRICT (7,8)

Alternative Water Supply	Present Cost $/mil gal	Actual Cost* $/mil gal	Energy kwh/1000 gal	TDS mg/1
Reclaimed Water				
1. Lime/Reverse osmosis treated	780	780	8.5	50
2. Present blend of Activated Carbon/Reverse osmosis+well water	836	836	9.2	680
Colorado River Water	320	832	6.4	750
State Water Project	320	933	10.2	300

*Cost reflecting actual power cost and without ad valorem tax subsidy.

Public Health. Although technology is available today to treat sewage to meet traditional drinking water standards, concerns over effects of reclaimed water on public health persist. This is because of limited knowledge in several areas related to reclaimed water reuse, particularly stable organics and virus removal, long term effects of ingesting trace organics as well as the bioaccumulation of heavy metals. The difficulties in assuring the continuous reliability of treatment processes whereever public contact is involved present a challenging problem. Present methods of reliability assurance are very costly. Further research is needed to evaluate capabilities of various treatment processes and improve the reliability of available technology to produce reclaimed water of suitable quality at reasonable costs. Because of the major potential for using reclaimed water for recharge of groundwater used as a domestic water supply, health related water quality criteria must be developed.

The farming community has been reluctant to use reclaimed water because of the concern that the marketability of crops irrigated with reclaimed water may be reduced. California health regulations allow the use of highly treated wastewater for irrigation of food crops, but often the cost of such highly treated water is not competitive with other irrigation water. Most of reclaimed water used in California's agriculture is for irrigation of pasture, fodder, fiber, orchards and seed crops where health concerns are minimized and where adequate water quality can be provided by less costly treatment schemes.

Institutional/Legal. In most instances, the agencies that develop, deliver and regulate water supply are separate from those that collect, treat, and discharge wastewater. This is true for agencies at the local level as well as at the state and federal levels. At the local level, this presents a constraint because it is often difficult to bring together the wastewater treatment agency which produces the reclaimed water, and the water purveyor who is usually the logical seller of reclaimed water. The constraint presented by such separation at the state and federal levels is more subtle, but just as significant. For California where the quantity of the water and the quality of the water are strongly related, such separation presents a definite constraint.

There are laws in California that were originally instituted to protect water purveyors, but now present a constraint to reuse of wastewater. For instance one law prohibits the installation of a duplicate distribution system, required for delivering reclaimed water, without reimbursing the original water purveyor. Another institutional constraint to reuse is the adverse financial impact on water suppliers which may be caused by the use of reclaimed water in the supplier's service area.

All of these constraints exist because up to now there has been no accomodation for reclaimed water in the water supply industry. As institutional and legal arrangements are changed to bring reclaimed water into the total water supply picture, these constraints will disappear.

Water Rights. Under California law, it has become apparent that the sale and distribution of reclaimed water may raise water rights questions regarding the ownership of the resource. These problems will arise both prior to the treatment of the water and subsequent to its discharge. Prior to treatment, a wastewater treatment facility may receive the wastewater from local sanitation districts. The districts normally convey the water through a sewage collector system after it has been discharged by local municipal and industrial users. Local users receive their water from either a municipal water supply system, a private water company, or through their own diversions. The water may be appropriated on the basis of overlying groundwater rights, riparian or appropriative water rights, or by contracts with the U.S. Bureau of Reclamation or the State Water Project. It is unclear under existing law who - the owner of the wastewater treatment facility or the water suppliers - may rightfully claim ownership of the treated effluent. Parties have commonly settled such questions through private agreements. In order to encourage the sale and distribution of reclaimed wastewater, it would be desirable to concentrate the ownership of the resource in one entity rather than in multiple entities. The Governor's Commission to Review California Water Rights recently urged that the owner of the wastewater treatment plant be granted the right to sell or distribute the reclaimed water.

Existing law now provides substantial judicial consideration of downstream rights to return flow thus creating a potential problem where the treatment plant owner proposes to produce and market reclaimed water. Commonly, downstream users will have obtained rights to the return flow that upstream users have discharged into the stream. Generally, upstream dischargers must respect the rights of downstream users to the return flow and this limits or even eliminates the dischargers ability to reuse their own wastewater.

Public Acceptance. Any program that considers the use of reclaimed water must take into account public attitudes toward such reuse. A recent study by William Bruvold of the University of California, Berkeley, surveyed public attitudes toward 25 general uses of reclaimed water in California. The use of reclaimed water for drinking and food preparation got the strongest opposition. The lowest level of opposition was directed to irrigation of golf courses and highway greenbelts, and road construction. The study concluded that the extent of opposition is correlated with the likelihood or extent of close personal contact. Fifty percent of the respondents in the study opposed the use of reclaimed water because the water was considered psychologically repugnant or lacked purity. The public perceives that foul-smelling, bad-tasting, dirty water is likely to contain harmful organisms or substances and that clear water, having no odor and a good taste, is not likely to be harmful. The goal of scientists, engineers, and health professionals in controlling the use of reclaimed water is to provide a reclaimed water of suitable perceptual quality for the intended use that is free from unacceptable risks posed by diseasecausing organisms or substances. Thus, the key to developing public acceptance of reclaimed water is a strong public information and educating program backed by solid scientific, engineering and medical evidence gained through well-publicized research and demonstrations.

Dissolved Mineral Levels. Level of dissolved minerals can limit reuse potential of given wastewater in most areas of reuse: agriculture, industry as well as groundwater recharge. To render wastewater with high mineral content suitable for reuse requires a high degree of treatment which may result in excessive costs. This is of particular concern in Southern California where mineral quality of the Colorado River water supply is marginal.

Water conservation measures, such as flow reduction, can lead to increase mineral concentrations in wastewater to the extent that subsequent reuse is not possible. Maintenance of optimal balance between water conservation measures and water reclamation is required to assure most efficient use of available water supply.

SWRCB ACTIONS TO ENCOURAGE RECLAMATION

In spite of the recognition of water reclamation potential, the legislative mandate and existing successful projects, only about seven percent of the 3.1 m acre-ft of municipal and industrial wastewater produced annually in California is reclaimed and reused.

To actively promote and encourage water reclamation, the State of California, particularly the State Water Resources Control Board, has taken several actions aimed at expansion of water reclamation and reuse. A major consideration was the fact that billions of dollars are currently being spent in California to upgrade municipal sewage treatment, and maximum benefits from these expenditures can be obtained when treated wastewater is being reclaimed. According to a recent survey, it will cost $5 billion for pollution control facilities to meet the needs of California's population in 1990. To build these facilities, the taxpayer will be making a tremendous investment. Without wastewater reclamation and reuse much of the highly treated water produced by these facilities will indeed be wasted to the ocean or some other saline or brackish body of water.

Recognizing the existing constraints mentioned previously, the State Water Resources Control Board adopted in 1977 a Water Reclamation Policy and Action Plan which outlined actions to eliminate or reduce existing constraints. The Policy and Action Plan gave directives to all segments of the State Board - planning, construction grants program, regulation, enforcement, research and demonstration as well as public information programs - to give additional consideration to reclamation. Specifically it:

- amended the regulations governing the State and Federal Clean Water Grant program administered by the State Board so that in the competition for funds reclamation will be given a higher priority.
- amended the State Water Rights regulations so that use of reclaimed water as an alternative source of water supply is fully examined in any new application for water rights or petition to change existing water rights.
- recommended new water rights legislation that will protect existing water rights when reclaimed water is used in place of fresh water. This is necessary because prior to adoption of this new legislation some water rights would be lost if they were not used.
- requested that the research program focuses on elimination of constraints to the major uses of reclaimed water.

This policy, in only two years of its existence, resulted in:

- A sharp increase in the number of grants for reclamation projects;
- new laws being enacted that promote reclamation and protect water rights of reclaimed water users, and
- increased research and demonstration efforts.

OFFICE OF WATER RECYCLING

While the Policy and Action Plan did much to encourage and clear the way for reclamation, there was still a need for an entity with the specific responsibility of leadership and coordination of all water reclamation activities. Governor Brown filled this need in October 1977 by creating the Office of Water Recycling (OWR) in Oct. 1977 within the State Water Resources Control Board. At the same time, the Governor established a five year goal of constructing facilities that will make available an additional 400,000 acre-ft of reclaimed water per year by 1982. In other words, the use of reclaimed water is to be tripled from the present 215,220 acre-ft/y to 600,000 acre-ft/y by Oct.1982. To put this in perspective, 600,000 acre-ft/y is equivalent to the combined yield of Auburn and New Melones Dams - or about two-thirds of the water needs of the City of Los Angeles.

To accelerate and encourage water reclamation activities OWR has developed a four-point strategy:

- Concentrate on large volume uses of reclaimed water such as agricultural and landscape irrigation, power plant cooling, and groundwater recharge.
- Emphasize uses with fewest constraints such as industrial uses where public health considerations can be minimized.
- Encourage reclamation through grants from the Clean Water Construction Grants Program (PL 92-500 Sec. 201) for water reclamation facilities.
- Inform potential users of reclaimed water of recent scientific and engineering developments by serving as the State's focal point for information exchange and public education in the area of reclamation.

The OWR is performing the following major functions:

- Implementation of planning studies with the objective to identify and develop markets for reclaimed wastewater;
- Administration of Clean Water Construction Grants for water reclamation projects;
- Identification and resolution of roadblocks to wider application of reclamation;
- Coordination of wastewater reclamation activities between federal, state and local agencies;
- Development of incentives for use of reclaimed water;
- Development and conduct of research and demonstration program;
- Serving as the State's focal point for technical information exchange and public education in the area of water reclamation.

OWR staff includes specialists in the area of public health, treatment technology, land application of wastewater, and industrial reuse as well as engineers administering and coordinating most of the Clean Water Grant reclamation projects. The following is a brief description of OWR's major programs.

PUBLIC INFORMATION AND TECHNOLOGY TRANSFER

A comprehensive information and public education program is a significant activity of OWR because of the importance of public acceptance for developing water reclamation to its full potential in California. Local agencies, industrial and agricultural water users, and the general public need factual information regarding the beneficial use of reclaimed water. The public information and education program includes publication of a monthly bulletin, and development of information brochures covering specific topics such as reclaimed water use for landscape irrigation, industry and agriculture, and detailed technology transfer reports dealing in depth with major water reuse applications. An industrial reuse conference was held in fall, 1978 and a symposium on "state of the art" of groundwater recharge is planned for September of this year.

CLEAN WATER GRANTS FOR WATER RECLAMATION

As noted previously, the Clean Water Grant Program is the major source for funding cost-effective reclamation projects. The current status of the Clean Water Grant project development is summarized in Table III.

TABLE III
GRANT PROGRAM RECLAMATION
PROJECTS IN CALIFORNIA
February 1978

Current Status	Number of Projects	Projected Reclaimed water flow, acre-feet/per year by 1982
Planning	76	259,000
Design	10	10,160
Construction	26	23,380
Construction Completed	28	99,610
Total	140	392,150

Presently, there are 112 reclamation Clean Water Grant projects in various stages of planning, design and construction. During recent years, twenty-eight projects have been completed and are providing 99,610 acre-ft of reclaimed water yearly for a variety of uses. If all of the projects presently in planning are implemented, 259,000 acre-ft/y of additional reclaimed water could be on-line by 1982. As nearly two-thirds of the wastewater generated in California is produced in the heavily populated urban centers, there will be a large increase in the amount of reclaimed water volume to be utilized for typically urban needs such as landscape irrigation and industrial uses.

REGIONAL WATER REUSE STUDIES

A major effort has been undertaken during 1978 through the Clean Water Grant Program to develop reclamation on a regional basis in California's major metropolitan areas - Los Angeles, San Francisco and San Diego. Taken together, these areas contain about 90 percent of the State's population. These studies will develop the necessary background information needed for implementation of potential reclamation projects in these areas. Major activities of these studies include:

- Detailed market survey;
- Engineering analysis of technical feasibility of identified potential projects;
- Institutional, economic and financial analysis of project feasibility and development of project financing methods; and
- Environmental assessment of proposed projects.

San Francisco Bay Area Regional Water Reuse Study. Fourteen Bay Area water and wastewater agencies, led by the East Bay Municipal Utility

District, have joined State and federal agencies to conduct a study to determine the feasibility of large scale water reuse in the San Francisco Bay Area and the Central Valley. Although the San Francisco Bay Area was severely impacted during the recent drought, less than one percent of the available Bay Area wastewater is being reused. The potential market for reclaimed water identified during the first phase of this study could utilize more than the amount of wastewater annually available from the Bay Area (623 mgd). The most significant markets found for Bay Area reclaimed water are agriculture in the Central Valley, Delta outflow augmentation for salinity control, and powerplant cooling. Total cost of the two year study is $2 million.

Orange and Los Angeles Counties Water Reuse Study. This regional reuse study will focus on the most critical area of California as far as water supply is concerned. Each year, the 8 1/2 million people and industry of Orange and Los Angeles Counties utilize almost 2 million acre-ft of water. A significant portion of the water need is imported - 85 percent in the City of Los Angeles, 60 percent in Orange County and 50 percent in Los Angeles County. Natural supplies provide only 35 percent of the total water need, and planned reuse accounts for about 3 percent. It is estimated that about 450,000 acre-ft of additional wastewater could be reclaimed in this area. The purpose of this study is to establish the engineering and economic feasibility as well as develop an implementation plan for maximum reuse in the area. This study, with its $4 million budget, is the largest of all regional studies currently underway in California and will be completed in 1981.

San Diego Water Reuse Study. Ninety percent of the water used in San Diego County is imported. The recently completed Areawide Water Quality Management Plan recommended water reclamation projects involving primarily agricultural and landscape irrigation. Twelve of the recommended projects have good potential for implementation. The regional reuse study will perform facilities planning for implementation of these projects which would provide up to 31,000 acre-ft/y. Total cost of this two year study is about $660,000.

INDUSTRIAL REUSE

Industrial water recycling has a potential to contribute significantly to the desired increase of water recycling in California and is often readily implementable because of its minimal public health impacts.

Because of increasing cost of fresh water supplies, wastewater disposal, and unreliability of fresh water supplies, industry should consider alternative water supplies and a more efficient use of water. The Office of Water Recycling intends to support industries in their water recycling effort. There are basically three ways industry may want to consider water recycling:

- in-plant recycling of its own effluent;
- use of reclaimed municipal wastewater which, due to stringent waste discharge requirements, is often treated to the level acceptable for use by many industries; or
- making industrial effluent available for reuse elsewhere.

OWR activities are designed to make industry aware of advantages of using reclaimed water and assist industries to convert to use of reclaimed water supplies without significant hardships.

OWR's plan of action to promote industrial recycling contains the following major program elements:

Technical Information Development and Transfer. Under this program element, OWR organizes conferences, seminars and workshops and is currently funding preparation of several technology transfer reports focusing on reuse of municipal wastewater for cooling, and on water recycling in food processing and pulp and paper industries.

Economic Incentives Development. OWR is presently exploring legislation to provide economic incentives for industrial recycling in a form of low cost equipment financing.

Assistance to Industries with Institutional Problems. OWR staff is available to help industries in their dealings with regulatory agencies.

To be fully effective in the above outlined program, OWR maintains liaison with industrial umbrella associations, major industrial companies, federal, local and other State agencies as well as with institutions involved in research and development of industrial water recycling.

As a part of the regional water reuse studies and several major Clean Water Grant projects, planning studies are underway to identify and develop potential markets for industrial reuse of reclaimed municipal wastewater. Particularly intensive efforts are being made by the Orange-Los Angeles Water Reuse Study, where no-obligation consulting engineering services are provided to all area industries and water purveyors interested in reuse of reclaimed water. Consultants will provide to potential reclaimed water users all information needed for feasibility assessment of reclaimed water reuse, and develop detailed plans to be followed by industries or water purveyors in order to take advantage of the reclaimed water supply.

RESEARCH AND DEMONSTRATION PROGRAM

The OWR research and demonstration program focuses on two major areas of water reuse, agricultural irrigation and groundwater recharge.

The objective of this research and demonstration program is to attain wider acceptance of reclamation and develop tools for implementation of reclamation projects. The following are the current major activities in each of the two areas.

Agricultural Activities. Over 80 percent of current use of reclaimed water is for irrigation purposes. About 69 percent is for agricultural irrigation and thirteen percent for landscape irrigation. By 1982 landscape irrigation is projected to sharply increase to about 30 percent of the total volume of reused wastewater. Reclaimed water use for irrigation could be further increased if several concerns of the farming community and regulatory agencies could be overcome. These concerns include public health and long-term effects of reclaimed water on soil and crops, price of reclaimed water as well as consumer acceptance. These concerns are the prime target of current and planned research and demonstration activities, which include the following:

A. Evaluation of Successful Agricultural Reuse Projects Using Reclaimed Water.

This project involves monitoring of several successful agricultural reuse projects with the objective to demonstrate to potential users and the agricultural community that use of reclaimed water is compatible with high quality and reliable agricultural production. The following data will be collected and evaluated:

1. Project description including: site, history of use, quality and treatment of applied reclaimed water, water quality and quantity requirements, soil and crop types, irrigation mode and season, documented effects on soil and crops;

2. Reasons why the reclaimed water is being used;

3. Public health considerations and steps taken for mitigating potential public health problems;

4. Project economics and marketability of crops;

5. Alteration of crop-cultivation and salt management practices caused by the use of reclaimed water.

Information obtained from these projects will be disseminated to farmers, irrigation districts and interested public. Emphasized will be projects most readily implementable because of lower treatment requirements such as those involving irrigation of fodder, fiber and seed crop, orchards, vineyards and pasture irrigation.

B. Monterey Agricultural Irrigation Demonstration Program at Castroville.

This pilot project is not unique in irrigating food crops with reclaimed water. The practice occurs elsewhere in the U.S. and the world. What is unique is the great detail in monitoring and documentation of the effect on plants, soil and public health. Over a five-year period, comparison will be made between chemical, physical and biological characteristics of soils, crops and waters in trial plots receiving ordinary well water, filtered secondary effluent or coagulated, filtered secondary effluent, as currently required by Department of Health for food crop irrigation. Cultural practices will duplicate those normally used by the area's farmers. The results will be evaluated to determine if statistically significant differences exist between the characteristics of soil and plants of different crops receiving different water types under different fertilizer application rates.

Groundwater Recharge Oriented Activities. The potential for increased use of reclaimed wastewater for groundwater recharge is great, particularly in Southern California where several existing projects could be expanded and new projects are being proposed. However, the lack of information on health effects and fate of pollutants such as viruses, trace organics and heavy metals in the underground environment is a major obstacle to expanding existing operations or implementing new groundwater recharged projects in

California.

To develop a research program that will provide the needed information required to establish reclamation criteria and design guidelines for groundwater recharge projects, the State Board, jointly with the Department of Health and the Department of Water Resources, sponsored in 1975 a consulting panel of nationally recognized health and water experts who identified research needed before comprehensive assessment of reclaimed water use for groundwater recharge can be made.

The following on-going research projects are implementing the panels recommendations:

A. A study of health aspects of groundwater recharge in the Montebello Forebay is being conducted by the Los Angeles County Sanitation District. The objective of this $1.2 million study is to assess the public health impact of the Montebello Forebay groundwater recharge operation. Information generated by this project will include epidemiological assessment, determination of water quality changes occurring during recharge, and identification of wastewater components of public health concern. Montebello Forebay is the largest groundwater recharge operation in the State (30 mgd) and has been in operation since 1962.

B. A study of groundwater recharge with reclaimed water at Ely Basin, to be conducted by Chino Basin Municipal Water District, will focus on pollutant removal by soil - particularly emphasized will be trace organics.

Both studies focus on groundwater recharge by spreading rather than injection. Spreading is considered in California a preferable method of groundwater recharge by reclaimed water because of the additional pollutant removal by the unsaturated soil zone through which reclaimed water percolates. Recharge by spreading has more potential for future application in California than recharge by injection. However, behavior of many pollutants, particularly stable organics, in soils and sediments in the underground environment is not adequately known. The assessment of soil capabilities for removal of pollutants is needed to determine the reclaimed water quality needed for groundwater recharge. Comprehensive knowledge of soil capabilities to remove pollutants may allow regulatory agencies to reduce present high treatment requirements for reclaimed wastewater quality.

CONCLUSION

It is clear that water reclamation will be playing a more and more important role in meeting California's water needs. Not only will good use be made of a valuable resource, but significant water quality benefits may also be achieved. Where reclaimed water is applied to land for irrigation, effluent which otherwise may be discharged to surface waters is being used on land. Particularly, in California, where water quantity and quality are closely related, surface water supplies saved through reclamation can be used to reduce groundwater overdraft and repell salt water intrusion.

Water reclamation has an excellent potential; however, implementation of large scale reclamation cannot, of course, be accomplished by State government alone. It will require not only strong support from federal agencies, but full acceptance of reclaimed water as an alternative water supply by all parties involved: water districts, the farming community, industry as well as the general public.

Wastewater reuse is consistent with the national goal to eliminate the discharge of pollutants into navigable waters by 1985, as stated in U. S. Public Law 92-500 and reaffirmed in 1977 by U. S. Public Law 95-217, as well as with California's need for the most efficient use of its limited resource - water. In its activities, the Office of Water Recycling thrives for wider utilization of water reuse and for eventual development of the maximum water reclamation and reuse potential in the State. It is hoped that accomplishment of these goals will improve California's water supply situation and contribute to water resources management which will be most beneficial to California's economic and environmental welfare.

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THE POTENTIAL FOR WASTEWATER REUSE IN THE UNITED STATES

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INTRODUCTION

This paper describes the results of a study for the Department of Interior, Office of Water Research and Technology on the potential for wastewater reuse and recycling in the Nation in 1985 and 2000. The basic data for water supply, water needs and availability, and wastewater discharges are derived from information developed by the U.S. Water Resources Council (WRC) for the Second National Water Assessment which was released in draft form in April, 1978. The WRC data for the Nation are compiled for 21 major water resources regions and 106 subregions; the 21 regions are shown in Figure 1.

The terms recycling and reuse are used throughout this paper. Recycling is defined as the internal use of water by the original user prior to discharge to a treatment system or other point of disposal. The term reuse is applied to wastewaters that are discharged and then withdrawn by a user other than the discharger.

The purposes of the study included: (1) develop information necessary to estimate the potential for wastewater reuse in the United States in 1985 and 2000, and (2) report the estimates for water recycling developed by the U.S. Water Resources Council and others. The major effort in this study was directed toward developing estimates of the potential for wastewater reuse because this had not been done for the entire Nation.

Recycling estimates are given in this paper for industries and steam electric plants. The recycling estimates were made by the Water Resources Council and are based on studies by the Council, the Department of Commerce, the Bureau of Mines and the Federal Power Commission (now the Federal Energy Regulatory Commission in the Department of Energy).

The sources of wastewater and water users that could substitute reclaimed wastewater for fresh water (these users are called "water withdrawals capable of wastewater reuse" in this paper) are divided into the following categories:

Wastewater Discharges Available for Reuse	Water Withdrawals Capable of Wastewater Reuse
Agricultural Irrigation	Agricultural Irrigation
Steam Electric	Landscape Irrigation
Industry	Steam Electric (Cooling)
Municipal	Industrial Cooling
Fish Hatcheries	Industrial Other

The quantity of reclaimed wastewater used for municipal purposes, other than landscape irrigation, is not estimated in this study for two reasons: (1) there are unresolved questions on the health aspects of using wastewater that will limit its potential for municipal use in the near future, and (2) the quantity of water required for potable purposes is small in comparison to other requirements.

Two relatively new Federal Laws will have a significant impact on the quality of wastewater discharges and water reuse: The Safe Drinking Water Act (PL 93-523) and the Clean Water Act of 1977 (PL 95-217). The Safe Drinking Water Act provides regulations for drinking water but will indirectly affect the quality of wastewater because many wastewaters are discharged into streams that are also used for public water supplies. One purpose of the Clean Water Act of 1977 is to achieve greater use of systems which reclaim and reuse water and productively recycle wastewater. The Clean Water Act will also improve the general quality of wastewater through more stringent control of industrial waste discharges.

WATER REQUIREMENTS

The WRC Assessment presents different water use estimates for agricultural irrigation and steam electric purposes based on the dryness of the year. All of the data used in this study are based on dry year conditions. Water requirements and wastewater discharges were determined for 1975, 1985 and 2000. Fresh water withdrawals in 1975 are shown in Figure 2 and the following tabulation summarizes the national total fresh water withdrawals and wastewater discharges in billion gallons per day (bgd) for 1975 and 2000.

	Water Withdrawal			Wastewater Discharge		
	Quantity, bgd 1975	Quantity, bgd 2000	Percent Change 1975-2000	Quantity, bgd 1975	Quantity, bgd 2000	Percent Change 1975-2000
Agriculture	184.7	180.3	- 2	84.7	72.0	- 15
Steam Electric	89.1	80.1	-10	87.7	69.5	- 21
Manufacturing	51.2	19.7	-62	45.2	5.0	- 89
Municipal	28.8	37.1	+29	21.4	27.6	+ 29
Minerals	7.1	11.3	+59	4.9	7.7	+ 57
Public Lands	1.2	1.7	+42	0.003	0.006	+100
Fish Hatcheries	0.6	0.7	+17	0.6	0.7	+ 17
TOTALS	362.7	330.9	- 9	244.5	182.5	- 25

These data show that fresh water requirements, as represented by withdrawals, for agriculture and steam electric plant cooling decrease somewhat (2 and 10 percent respectively). Manufacturing requirements are estimated to decrease by over 60 percent by the year 2000 and requirements for municipal purposes, minerals industries and public alnds are projected to increase. Wastewater discharges from agriculture, steam electric plants and manufacturing industries are estimated to decrease by the year 2000 and discharges from municipalities and minerals industries are estimated to increase.

It is estimated that agriculture and steam electric plants will continue to use over 75 percent of all fresh water withdrawn in the United States

	Percent of Total Fresh Water Requirement	
	1975	2000
Agriculture	50.9	54.5
Steam Electric	24.6	24.2
Manufacturing	14.1	6.0
Municipal	8.0	11.2
Minerals	1.9	3.4
Public Lands	0.3	0,5
Fish Hatcheries	0.2	0.2

About 99 percent of agricultural water use is for irrigation. Agricultural irrigation is the largest current, and projected future, water user in the Nation and presents opportunities for significant water conservation and reuse. Most of the demand (63 percent of national total) for agricultural water is in the Pacific Northwest, California and Missouri regions as shown in Figure 3.

Landscape irrigation requirements are small in comparison to other major uses, but it is included as a separate category in this paper because reclaimed wastewater can be used to supply a significant part of the requirement. The total landscape irrigation use in 1975 was estimated to be 1.2 million acre-feet and Figure 4 shows that no single region used more than 14 percent of the total. This total does not include residential irrigation of lawns and landscaping. The following summary shows information for the three regions with the highest landscape irrigation use in the Nation.

	Landscape Irrigation		
Region	1,000 acre-feet/year	Percent of Total Annual Water Use Within Region	Percent of Total U.S. Landscape Irrigation
California	174	0.4	14
South Atlantic Gulf	133	0.5	11
Great Lakes	127	0.3	10

Cooling water for steam electric generating plants represents the second largest requirement for fresh water in the Nation (89 bgd in 1975 and 80 bgd in 2000). Most of the demand is in the Eastern United States with the Great Lakes and Ohio regions accounting for over 50 percent of the total national requirement (see Figure 5). Recycling is projected to increase substantially by the year 2000 and there is potential for using reclaimed wastewater to supply a significant part of the requirement for makeup water.

Industrial requirements and discharges are estimated for the following manufacturing and minerals Standard Industrial Classifications (SIC):

Manufacturing Industries

Primary Metals - SIC 33
Chemicals and Allied Products - SIC 28
Paper and Allied Products - SIC 26
Petroleum and Coal Products - SIC 29
Food and Kindred Products - SIC 20
Transportation Equipment - SIC 37
Textile Mills Products - SIC 22
Other Manufacturing

Minerals Industries

Metal Mining - SIC 10
Non-Metal Mining - SIC 14
Fuels
  Anthracite Mining - SIC 11
  Bituminous Coal and Lignite Mining - SIC 12
Oil and Gas Extraction - SIC 13

Primary metals (SIC 33), chemicals (SIC 28) and paper (SIC 26) industries accounted for about 77 percent of the total fresh water requirements for manufacturing industries in 1975 (see Figure 6). The total fresh water requirement of these same three industry categories in 2000 is projected to be about 14 bgd or about 72 percent of the total industrial manufacturing requirement of 19.7 bgd. Most of the water use for manufacturing is in the Great Lakes, Ohio, Mid-Atlantic, South Atlantic-Gulf, Lower Mississippi and Texas-Gulf regions with the Great Lakes Region accounting for over 20 percent of all industrial use (see Figure 7).

Water use in manufacturing industries is primarily for three purposes: (1) cooling, (2) boiler feed, and (3) processing. About 70 percent of all industrial use is for cooling and this represents a potential for wastewater reuse and recycling. Boiler feed water and process water in general require higher quality water and the potential for reuse of wastewater for these purposes is more limited.

The minerals industries include metal mining (SIC 10), fuels (SIC 11, 12 and 13), and non-metal minerals (SIC 14). The largest water withdrawal is by the non-metal mining industry, but the largest consumer is the fuels industry with more than 60 percent of the total. The principal water using non-metal mineral industries are chemical and fertilizer mining (SIC 147), 51 percent of the total and sand and gravel (SIC 144), 30 percent of the total. Over 90 percent of the water withdrawn by non-metal minerals industries was for coal processing with very little used for cooling. Non-metals will continue to be the major water using segment of the minerals industries with an increase from 3.7 bgd in 1975 to 6.1 bgd in 2000. Reclaimed wastewater could be used for several purposes, including processing, in some minerals industries.

WATER AVAILABILITY

The Water Resources Council found in the Second National Water Assessment that, overall, the Nation's water supplies generally are sufficient to meet the requirements for all beneficial purposes. However, there are major water supply problems in most of the 21 regions and severe local problems in many of the 106 subregions. These problems include: shortages resulting from inadequate distribution systems, ground water overdrafts, quality degradation of both surface and underground supplies, institutional constraints and competition between various uses.

The WRC Assessment concludes that the problem of inadequate water supply is currently severe in 14 of the 106 subregions located mainly in the Southwest and Midwest and estimates that, by the year 2000, inadequate supplies will be a problem in 24 subregions. Severe domestic rural water supply shortages were identified in half of the 106 subregions.

The relationship between fresh water availability and requirements is shown in Table 1 for each water resources region. These data indicate the regions, such as Alaska, New England and Tennessee, where large amounts of fresh water, in relation to requirements are available; and others, such as the Lower Colorado, Rio Grande and California, where fresh water availability is a problem.

EXISTING WASTEWATER REUSE

Existing wastewater reuse projects in each WRC subregion were determined in this study. The existing total reuse is estimated to be about 680 bgd or about 760,000 acre-feet per year.

	Existing Wastewater Reuse in the U.S. (thousand acre-feet/year)	
Irrigation		471
Agricultural	223	
Landscape	37	
Not Specified	211	
Industrial		240
Process	74	
Cooling	159	
Boiler Feed	7	
Ground Water Recharge		38
Other (recreation, fish and wildlife, etc.)		11
TOTAL		760

The estimated 760,000 acre-feet of wastewater that is reused in the United States is divided among about 536 locations. There are wastewater reuse projects in 49 of the 106 WRC subregions with the largest volume usage in Arizona and California and the greatest number of users in Texas and California.

Region	Number of Projects	Wastewater Reuse (thousand acre-feet/year)
Lower Colorado	36	204.4
California	283	192.3
Mid-Atlantic	7	130.5
Arkansas-White-Red	31	84.1
Texas Gulf	102	57.4
Pacific Northwest-Columbia	14	29.0
Rio Grande	24	22.0
Great Lakes	13	10.8
South Atlantic-Gulf	6	7.4
Missouri Basin	9	6.8
Great Basin	3	5.6
Upper Mississippi	2	3.0
New England	1	3.0
Upper Colorado	1	1.2
Ohio	2	1.1
Hawaii	1	1.0
Caribbean	1	0.4
TOTAL	536	760

POTENTIAL WASTEWATER RECYCLE

The large decreases projected in fresh water requirements and wastewater discharges for the steam electric and manufacturing industries are the result of large projected increases in water recycling. Recycling in manufacturing industries and steam electric plants is projected to increase substantially by the year 2000 as shown in the following summary.

	Fresh Water Recycled, bgd		Recycle Rate	
	1975	2000	1975	2000
Steam Electric	57	517	1.6	7.5
Manufacturing Industries	61	316	2.2	17.1
Minerals Industries	21	32	4.0	4.0
TOTAL	139	865	1.9	8.8

The estimate shown above is that fresh water withdrawn by steam electric plants in the year 2000 will be used 7.5 times before it is discharged as wastewater; fresh water supplied to manufacturing industries in the year 2000 will be used over 17 times before it is discharged. These data are also illustrated in Figure 8. The recycling by manufacturing industries results in a 62 percent decrease in the amount of fresh water required by 2000 and decreases the requirement for manufacturing from about 14 percent of the national total in 1975 to 6 percent in 2000.

POTENTIAL WASTEWATER REUSE

Wastewater discharges available for reuse are divided into treated and untreated quality categories in this paper. Treated wastewater includes (1) secondary effluent from municipal wastewater treatment plants, (2) industrial discharges treated by best available technology, (3) discharges from steam electric plants, and (4) discharges from fish hatcheries. Untreated wastewaters are agricultural irrigation return flows that could be collected and reused. Most irrigation return flows which reach streams through ground water flow or unconcentrated overland flow are not considered available for direct planned reuse. These discharges may become a part of stream flow and subsequently be withdrawn and used. However, reuse of this type is not planned and is not quantified in this report. Wastewaters from livestock use, rural domestic use and public lands are not considered available for reuse because they are relatively small quantities in generally remote locations.

The following users are capable of substituting wastewater for fresh water withdrawals:

Use Category	Wastewater Quality Required
Agricultural Irrigation	Treated
Landscape Irrigation	Treated
Steam Electric	Treated or Untreated
Industrial Cooling	Treated or Untreated
Other Industrial	Treated

Although ground water recharge is not considered a use, per se, ground water recharge is an important element of many existing and proposed wastewater reuse programs. The potential use of reclaimed wastewater for potable purposes, or municipal use other than landscape irrigation, is not estimated in this paper; however, municipal wastewater is a source for potential use in any of the above categories.

Some uses of wastewater may require additional treatment in specific locations. For example, some industrial uses may require clarification and filtration, nitrogen and phosphorus removal or desalting. Additional treatment may be required in some cases for wastewater used for cooling. Also, local regulatory agencies may require higher levels of treatment for some applications such as irrigation of food crops and irrigation of parks, playgrounds and schools.

Wastewater discharges available for reuse and requirements for fresh water that are capable of using wastewater as a substitute are shown in Figure 9. Data from this study summarized in Table 2 includes: (1) wastewater discharges available for reuse, (2) water withdrawals that are capable of using wastewater instead of fresh water, (3) actual and estimated potential wastewater recycling, and (4) actual and estimated potential wastewater reuse. These data are given for each of the 21 water resources regions in 1975 and 2000. The potential recycling estimates are based on studies by the U.S. Water Resources Council and others. The potential reuse estimates were developed in this study and are based on existing reuse, water availability in the region and other factors. The estimated reuse in the year 2000 ranges from 1 mgd in the Souris-Red-Rainy and Alaska regions to 1,139 mgd in the Missouri region; reuse of 733 mgd and 696 mgd are estimated for the Lower Colorado and California regions respectively. Over 50 percent of the reuse in 2000 is projected to occur in the Missouri, Lower Colorado and California regions.

CONCLUSIONS

The projections for the Nation in 2000 are as follows:

		Quantity, bgd
Water withdrawals capable of wastewater reuse		290.3
Agricultural Irrigation	177.8	
Landscape Irrigation	1.4	
Steam Electric	80.1	
Industrial Cooling	16.9	
Industrial - Other	14.1	
Treated wastewater discharges available for reuse		109.6
Steam Electric	69.5	
Industry	12.7	
Municipal	26.7	
Fish Hatcheries	0.7	
Untreated agricultural discharges		11.5
Wastewater reuse		4.8
Wastewater Recycle		865.5

It is estimated that (1) wastewater reuse will increase from 0.2 percent of fresh water withdrawals, capable of using wastewater, in 1975 to 1.7 percent in 2000, and (2) reuse of available wastewater will increase from 0.4 percent in 1975 to 4 percent in 2000. Recycling in the steam electric, manufacturing and minerals industries is projected to increase to 865.5 bgd by the year 2000. It is therefore projected that recycling will continue to supply the bulk of the Nation's total requirements for fresh water and that total fresh water withdrawals will actually be reduced as a result of this increase in recycling.

Several factors will determine the quantity of wastewater that will actually be reused by the year 2000 including: (1) the geographical location of discharges and potential users, (2) the timing of wastewater discharges and the requirements of potential users, e.g., irrigation requirements vary with the season but municipal discharges are relatively constant throughout the year, and (3) the availability and cost of alternative supplies.

There are large regional differences in wastewater availability and reuse potential. In the Eastern states and Alaska the quantities of available wastewater discharges and the withdrawals capable of reuse are relatively in balance. In the Western states, the withdrawals greatly exceed the available wastewater. This difference is primarily due to agricultural irrigation requirements.

TABLE 1

WATER REQUIREMENTS AND AVAILABILITY

WRC Regions	Unit Available per Unit Required*		
	1975	1985	2000
1 New England	164	122	74.2
2 Mid Atlantic	44.2	32.8	22.9
3 South Atlantic - Gulf	47.8	34.3	23.1
4 Great Lakes	29.0	22.8	16.0
5 Ohio	100	71.1	41.3
6 Tennessee	131	63.8	37.3
7 Upper Mississippi	99.0	69.0	40.0
8 Lower Mississippi	106	92.7	75.6
9 Souris-Red-Rainy	48.0	27.9	13.2
10 Missouri	3.04	2.52	2.37
11 Arkansas-White-Red	6.34	5.80	5.65
12 Texas Gulf	2.75	2.95	2.85
13 Rio Grande	1.12	1.08	1.15
14 Upper Colorado	3.53	2.95	2.71
15 Lower Colorado	0.92	0.86	0.84
16 Great Basin	3.42	3.45	3.25
17 Pacific Northwest	19.3	16.1	15.6
18 California	2.68	2.55	2.39
19 Alaska	15,604	4,393	1,980
20 Hawaii	12.2	11.5	11.0
21 Caribbean	15.1	13.8	17.3
Regions 1 through 18	11.1	9.92	8.93

*Ratio of available to required water, e.g., New England region in 1975: 164 gallons available for each gallon required.

Source: Calculated from data in "The Nations's Water Resources, The Second National Water Assessment", by the U.S. Water Resources Council, Summary Report, p. 34, Draft Review Copy, April 13, 1978.

TABLE 2

(All figures are million gallons per day)

	WATER RESOURCES REGION	WATER WITHDRAWALS CAPABLE OF WASTEWATER REUSE		WASTEWATER DISCHARGES AVAILABLE FOR REUSE				WASTEWATER RECYCLE		WASTEWATER REUSE	
				TREATED		UNTREATED		ACTUAL	ESTIMATED POTENTIAL	ACTUAL	ESTIMATED POTENTIAL
		1975	2000	1975	2000	1975	2000	1975	2000	1975	2000
1	New England	3,615	1,424	4,563	2,108	0	0	2,134	16,284	3	13
2	Mid-Atlantic	13,757	8,009	16,261	10,036	0	0	8,680	58,131	116	224
3	South Atlantic-Gulf	22,645	25,311	18,799	17,180	653	833	16,071	127,414	7	192
4	Great Lakes	38,564	20,410	40,059	20,737	0	0	9,859	97,417	10	290
5	Ohio	32,514	13,913	33,018	12,443	0	0	19,032	112,417	1	118
6	Tennessee	7,030	5,475	7,076	4,880	0	0	2,732	29,199	0	41
7	Upper Mississippi	10,311	5,359	11,151	5,093	0	0	8,155	66,139	3	48
8	Lower Mississippi	14,249	24,405	9,000	18,132	722	561	10,453	52,982	0	108
9	Souris-Red-Rainy	256	594	211	54	3	28	123	308	0	1
10	Missouri	40,385	47,016	5,126	5,791	1,767	1,901	5,476	37,795	6	1,139
11	Arkansas-White-Red	13,489	13,542	1,848	1,773	390	346	12,530	42,479	75	147
12	Texas Gulf	16,704	14,355	3,452	3,659	283	171	24,448	136,241	52	430
13	Rio Grande	6,588	5,771	278	308	240	174	2,469	4,124	20	370
14	Upper Colorado	7,654	8,251	223	353	587	559	2,650	7,598	1	61
15	Lower Colorado	8,710	7,272	354	522	545	362	2,766	8,815	182	733
16	Great Basin	8,280	7,190	470	591	640	454	1,586	11,511	4	62
.17	Pacific Northwest	45,322	40,172	3,528	1,902	4,563	3,438	3,677	28,288	26	67
18	California	38,664	39,412	2,647	3,089	3,147	2,590	5,807	23,827	172	696
19	Alaska	196	592	234	295	0	0	438	3,704	0	1
20	Hawaii	1,813	1,173	300	205	178	88	197	808	1	7
21	Caribbean	619	616	318	452	0	0	29	44	1	6
	TOTALS	331,255	290,262	158,916	109,603	13,718	11,505	139,082	865,525	680	4,754

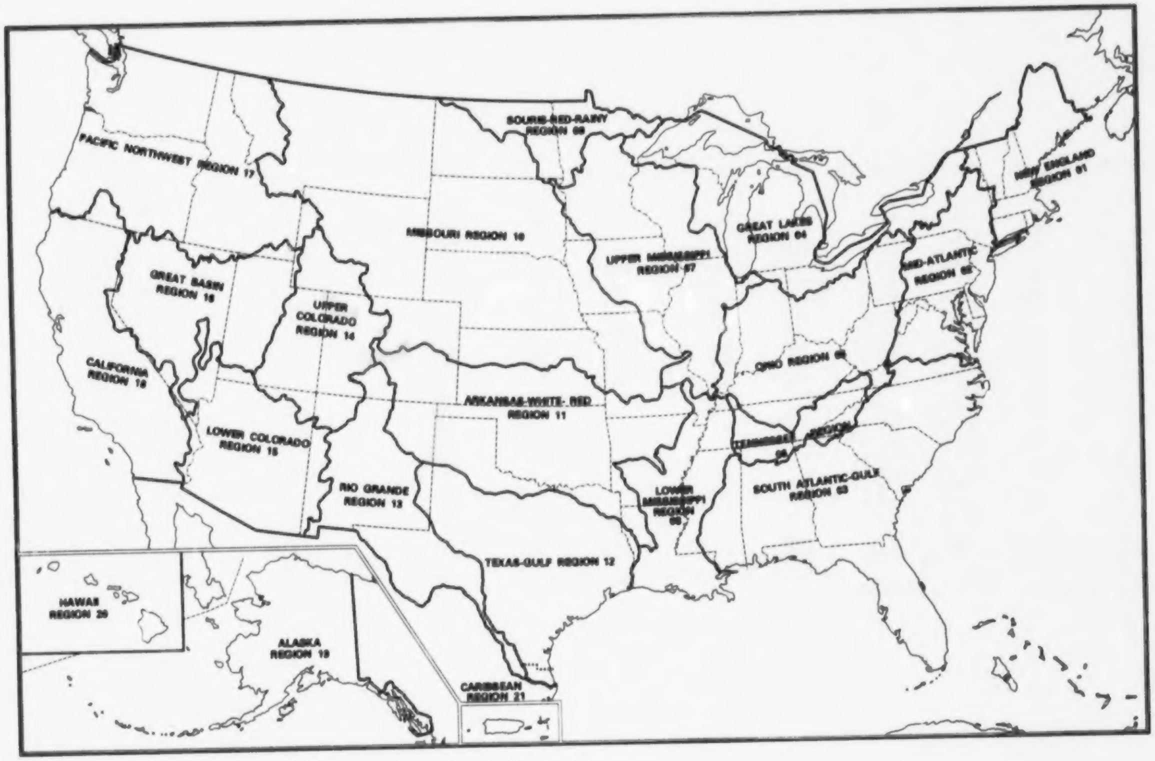

FIGURE 1 WATER RESOURCES COUNCIL REGIONS

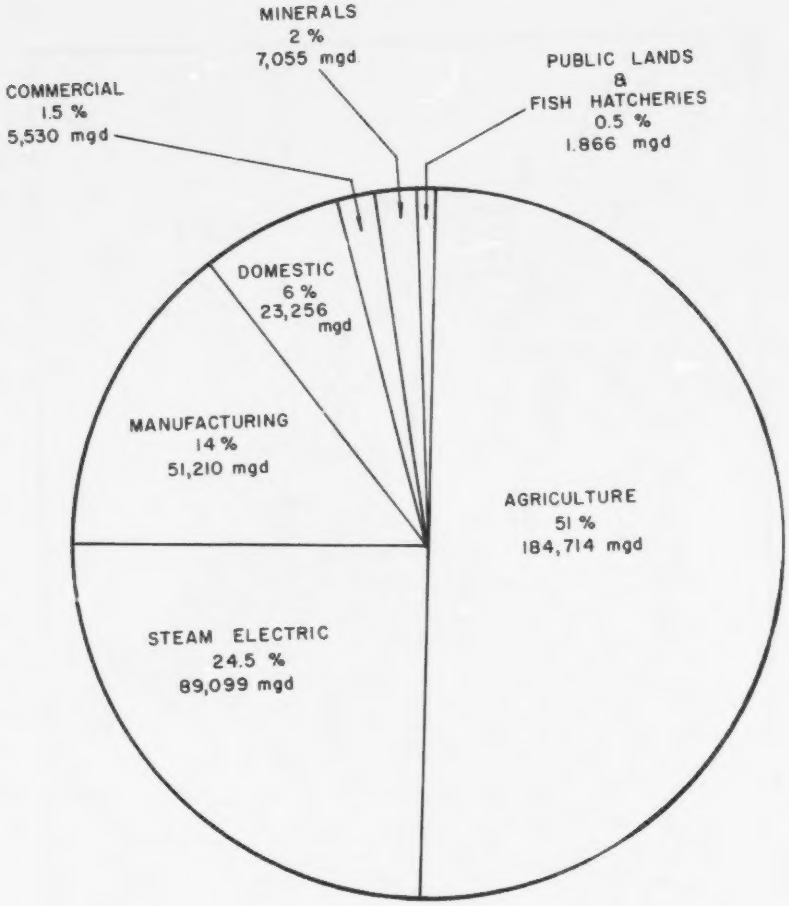

FIGURE 2. NATIONAL FRESH WATER WITHDRAWALS—1975

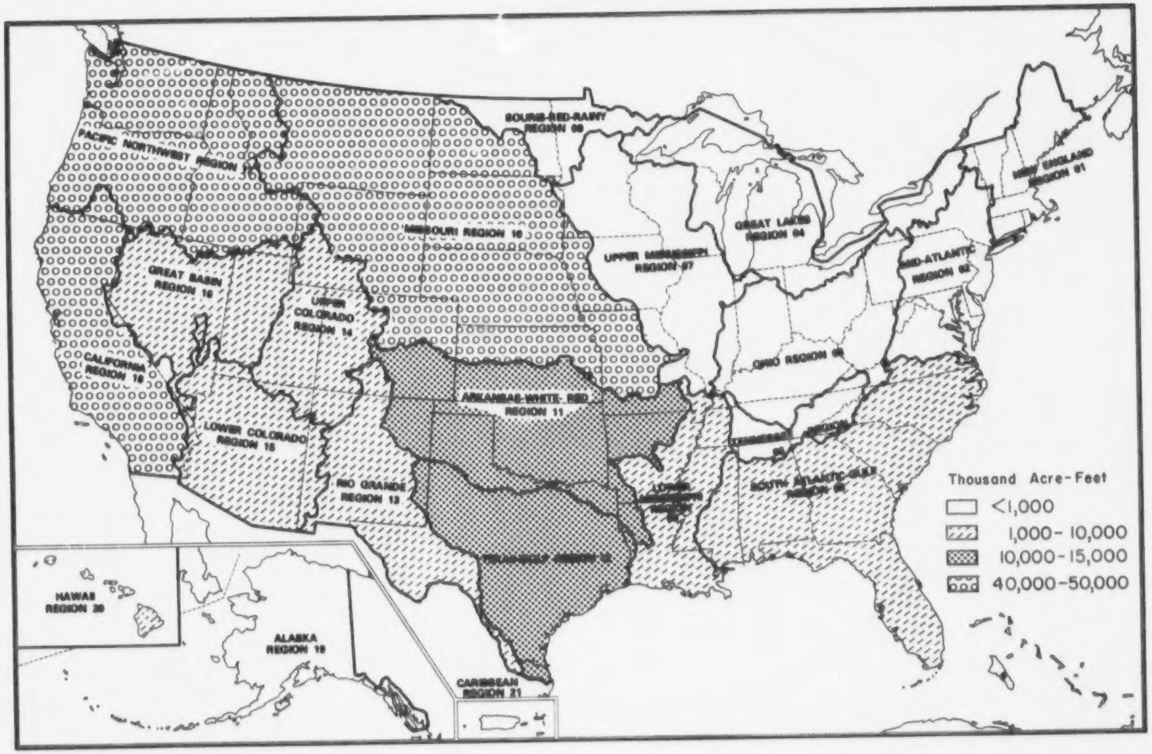

FIGURE 3. AGRICULTURAL IRRIGATION REQUIREMENTS—1975

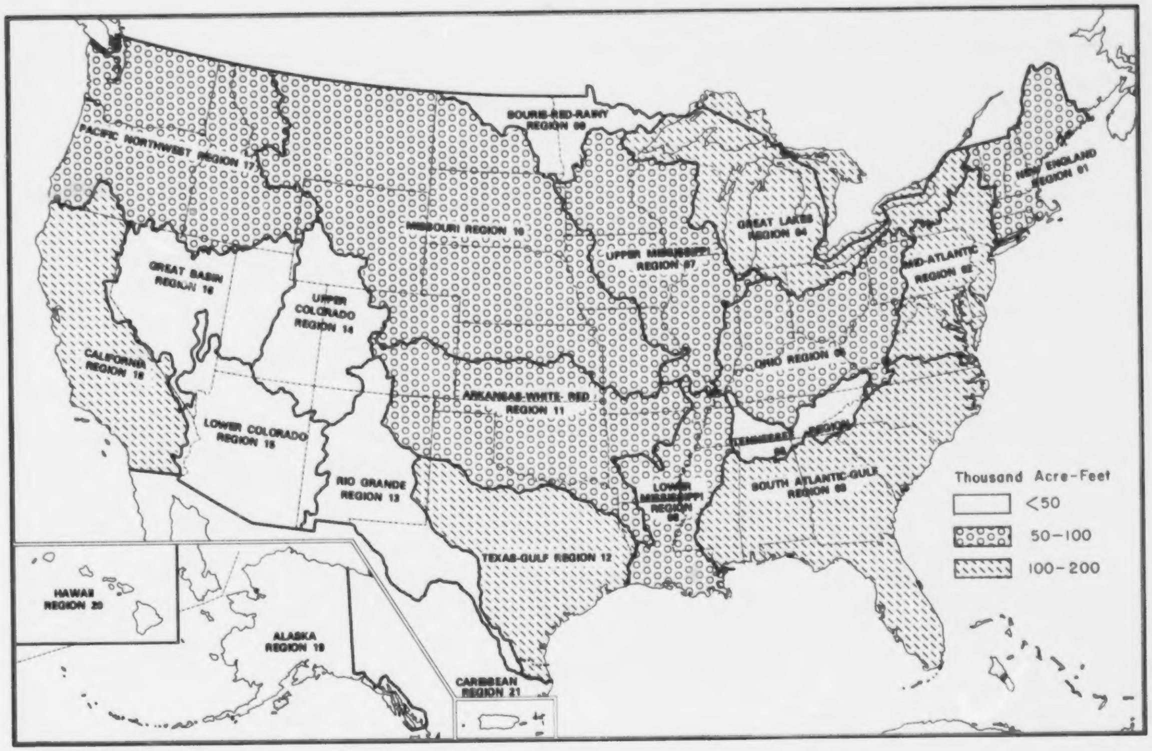

FIGURE 4. WATER USE FOR LANDSCAPE IRRIGATION - 1975

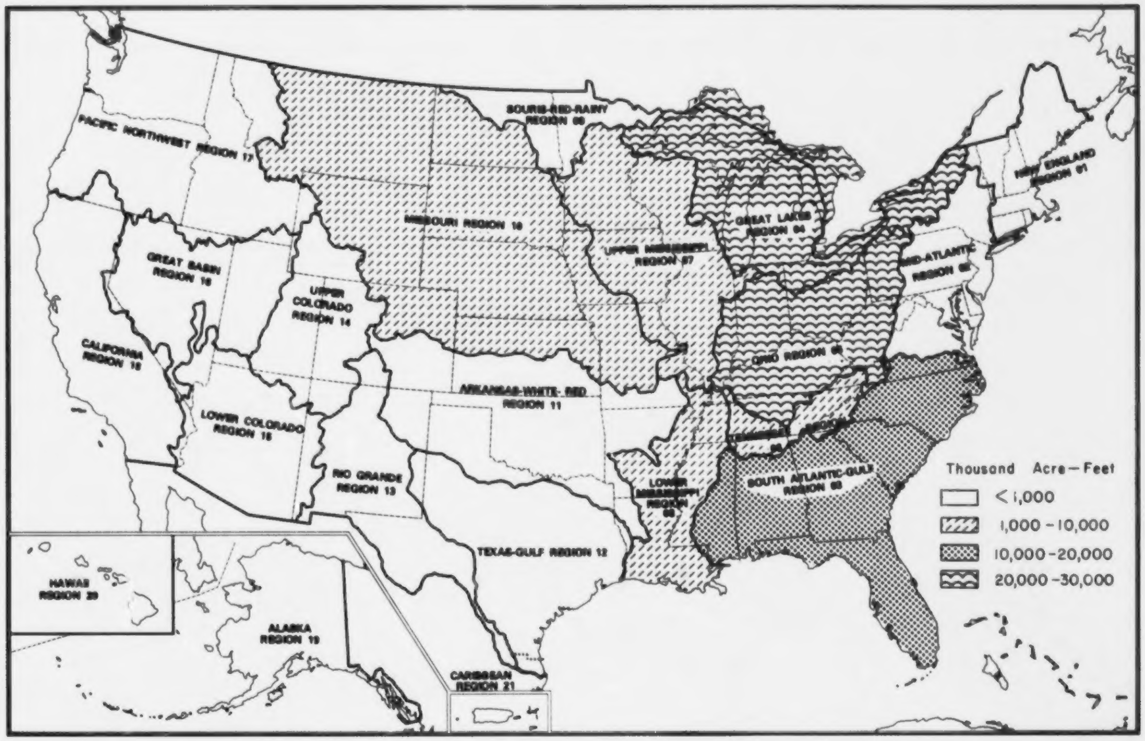

FIGURE 5. STEAM ELECTRIC WATER REQUIREMENTS - 1975

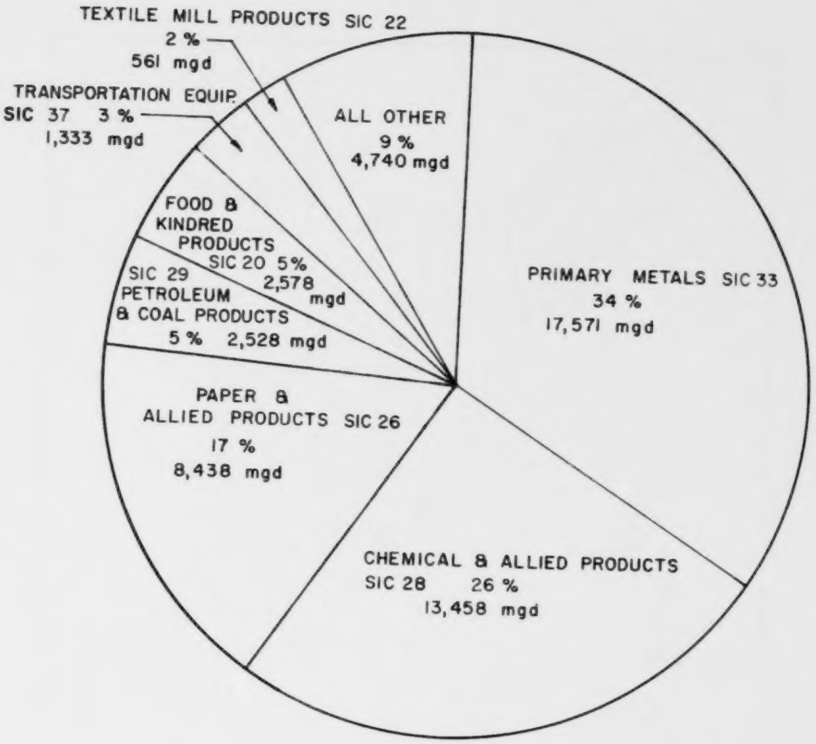

FIGURE 6. FRESH WATER WITHDRAWALS BY MANUFACTURING INDUSTRIES–1975

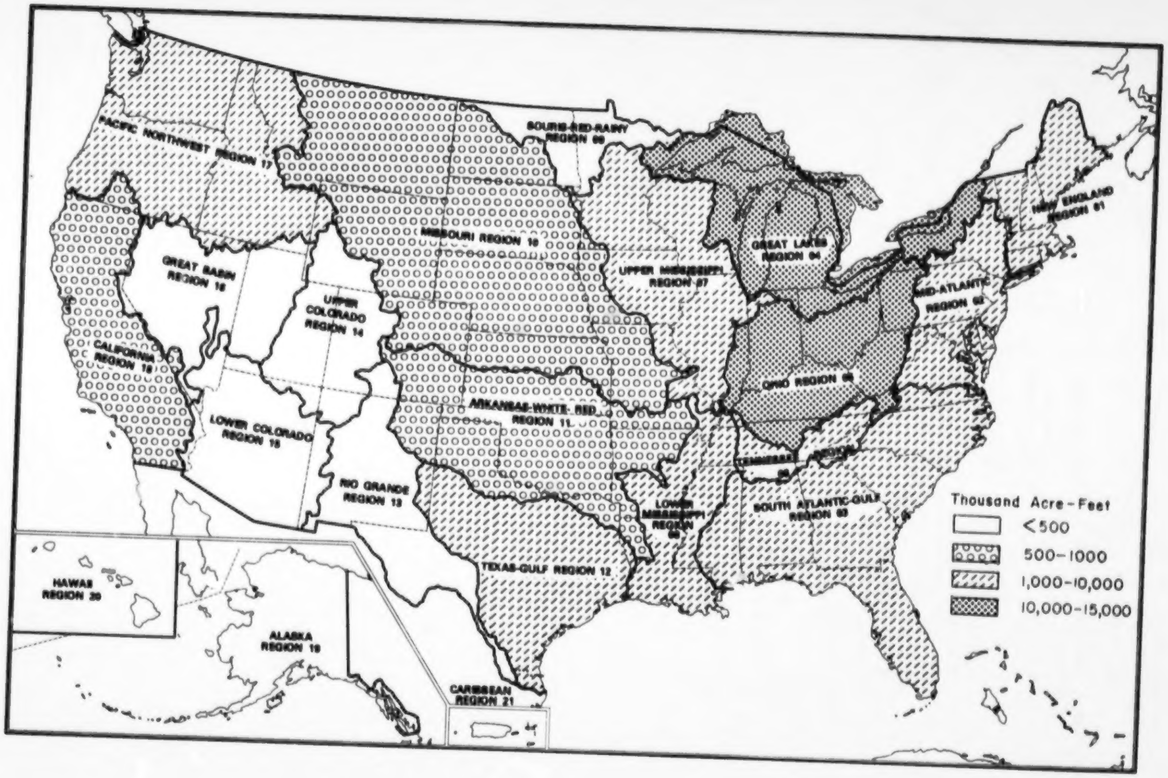

FIGURE 7. WATER REQUIREMENTS IN MANUFACTURING INDUSTRIES-1975

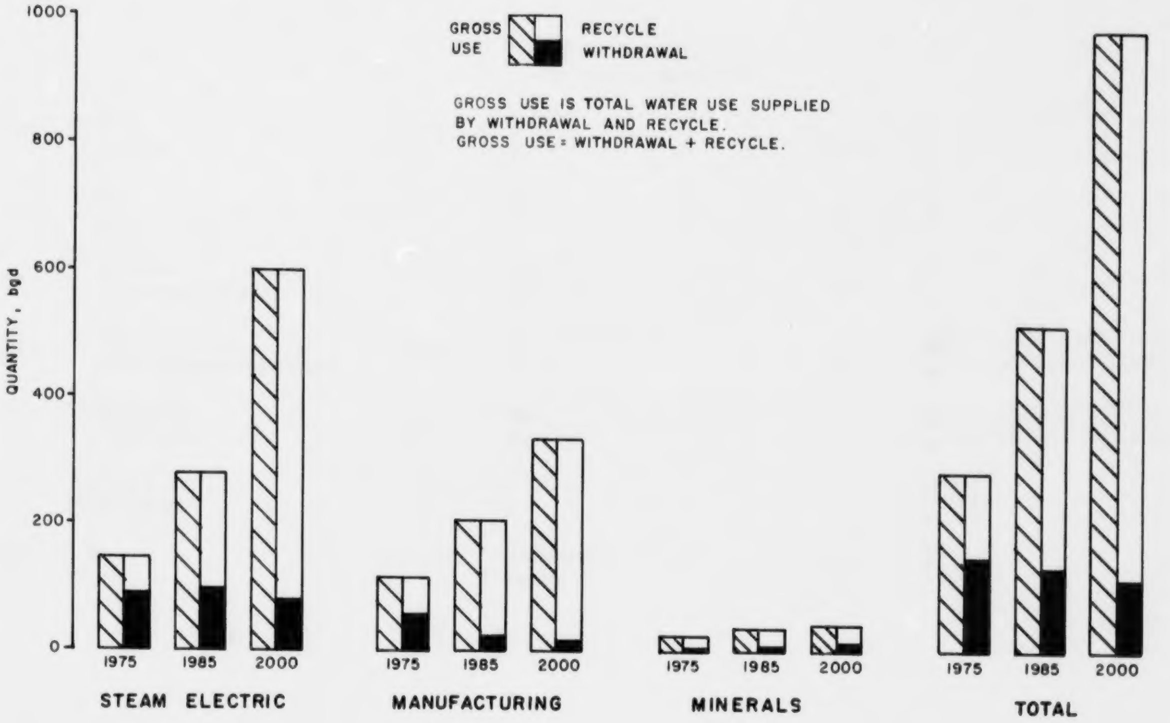

FIGURE 8. WATER USE BY STEAM ELECTRIC, MANUFACTURING AND MINERALS INDUSTRIES IN THE UNITED STATES

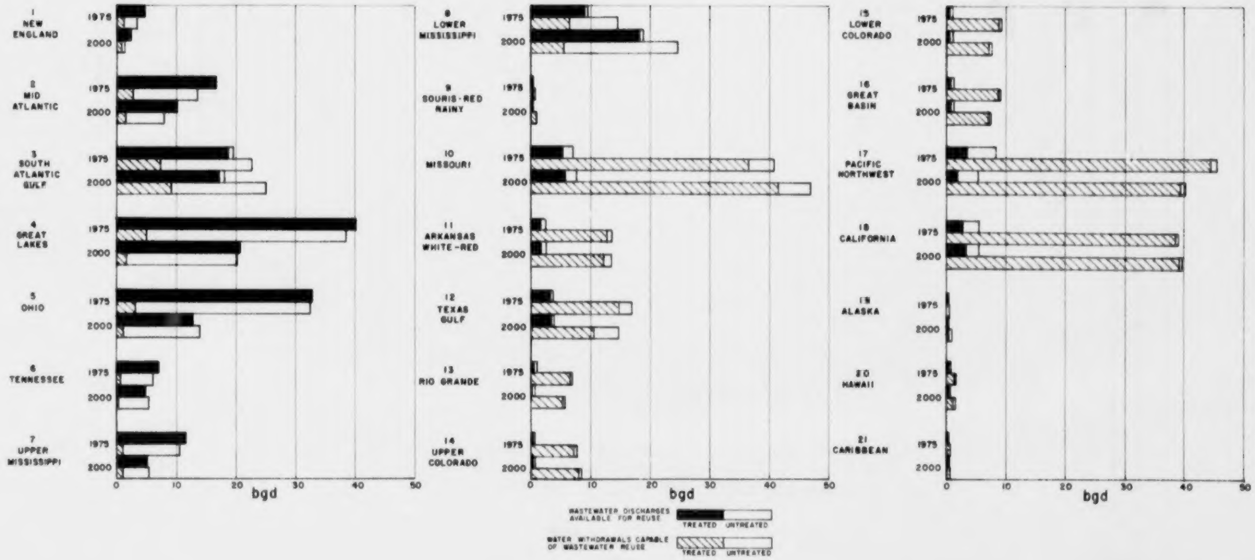

FIGURE 9. WASTEWATER DISCHARGES AND WATER WITHDRAWALS

WATER SUPPLY AUGMENTATION

DEMONSTRATION OF POTABLE WATER REUSE TECHNOLOGY

THE DENVER PROJECT

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The Denver Water Department (DWD) provides water service to over 900,000 people serving approximately 75 billion gallons (0.28 X 10^9 M^3) of treated water annually. The Department also supplies raw water, by agreement, to numerous cities and water districts around the Denver metropolitan area. To accomplish this, the utility operates an extensive raw water collection, storage, and transmission system which involves facilities for diversion of both native, indigenous water on the Eastern side of the Rocky Mountains and Colorado River water from the Western side. The entire raw water system operates by gravity and is controlled by releases from storage and regulating reservoirs.

It is the diversion of West Slope water and the rights to reuse it that have enabled the Denver Water Department to evaluate the various alternatives for successive use of water.

Denver, with its eye toward the future, realizes that continued growth in this water short area will create new demand and necessitate additional raw water supply capabilities. Since the native water supply is essentially fully utilized, within the context of Colorado water law, it is apparent that future supplies will necessarily derive from additional transmountain diversion and other alternatives to conventional acquisition of raw water. Evaluation of future West Slope diversion shows that this type of raw water acquisition will become increasingly more difficult and will have a major economic impact. Future diversions will require elaborate and lengthy transmission systems, and may involve pumping at

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a cost estimated to reach $5,000 to $6,000 per acre foot ($4,065 to $4,878/$10^3 M^3$) by the turn of the century. Therefore, while continuing to develop conventional raw water diversion, Denver is pursuing various non-conventional alternatives for increasing water supply, including successive use.

PROGRAM HISTORY

The Denver Water Department began its successive use program in the late 1960's. Initially the program involved the examination of water reuse alternatives including industrial and agricultural applications. Legal, marketing, planning, and other feasibility studies were performed concurrently with the design and construction of a small scale pilot facility. This facility (1) was developed jointly with the University of Colorado and provides a flexible laboratory for graduate research in the area of advanced waste treatment.

Evaluation of water use within the Denver area along with marketing studies to determine potential uses of a lower quality water led to the conclusion that the metropolitan area has neither the type nor volume of industry required to make industrial reuse of water feasible from either an economic or net yield standpoint. In addition, the evaluation of Denver's geography and current downstream uses of Denver's return flow led to the conclusion that intentional agricultural reuse of transmountain waters would not provide sufficient water for the future. Geology has also figured heavily in Denver's early dismissal of groundwater recharge as a viable alternative for water reuse. Denver is located over a geological bowl comprising the downward extension of the Rocky Mountains. The aquifers are extremely deep and very marginal in permeability.

It became apparent then that if the Water Department wished to maximize the benefits of successive use, essentially obtaining a new source of raw water, it must look further and find other forms of successive use.

In 1973, the Department, in conjunction with a corporate developer, evaluated the possibilities of dual distribution systems and the successive use of water through home irrigation and non-potable in-house uses. It was the conclusion of this study that dual distribution and non-potable reuse could indeed be practical in the Denver area. This conclusion, however, was contingent upon expansion of service to a previously undeveloped area to allow necessary service pipe installations without interference with existing utilities. This conclusion was also based on a population of 10,000 or more or an annual water usage of 3 million gallons per day at one location. At a level lower than that, economics and other institutional problems prohibited any substantial benefits through such a program.

An additional form of reuse evaluated by the Department is that of exchange. Exchange is the simplest form of successive use involving no treatment and relatively low cost, and is thus the most attractive. Denver has implemented exchange, the trading of used water at the sewage treatment plant outfall for less polluted water at existing intakes. Unfortunately, the amount of relatively unpolluted water available in the South Platte River is severely limited and therefore exchange will not utilize all of the return flow resource available.

The only form of successive use which would provide substantial benefit in terms of augmenting present water supplies was - and is - that of potable reuse. In Denver's case, potable reuse is the complete renovation of wastewater to a potable quality water which could, without reservation or restriction, be supplied through the potable system to the residents of the Metropolitan area.

CONCEPT OF A DEMONSTRATION PLANT

Because of the untested nature of potable reuse technology, most national experts agree that any process involved must be demonstrated on a plant scale prior to actual application.

In December, 1974, the Denver Water Department hosted a seminar to combine the knowledge of various consulting engineers and prominent technical experts associated with universities and State and Federal agencies with its own staff and co-workers at the University of Colorado. The idea of the seminar was to put this vast amount of knowledge together to design, in concept, a treatment process capable of treating a wastewater reliably and consistently to a high quality safe for human consumption. While the recommended treatment scheme did not represent the unanimous concept of the people whose advice was sought and considered, it did represent a consolidated opinion.

In early 1975, the Denver Water Department charged the consulting firm of CH$_2$M Hill with developing a preliminary design (2) for a potable reuse demonstration plant based on their knowledge and the advice and opinions presented in the seminar. The resulting process train is shown in Figure 1. The unit processes proposed for inclusion may be grouped into six removal or control operations as follows:

1. Phosphorous Removal
2. Suspended Solids Removal
3. Nitrogen Removal
4. Soluble Organic Removal
5. Dissolved Salts Removal
6. Disinfection

Under each of the preceding categories, there are one or more unit processes capable of achieving a desired result. Some of the primary processes under each category are shown in Figure 2. Since the initial process selections, in 1975, advances in technology and operating experience at both pilot and full-scale facilities has provided data on each of these control processes. The selection of a specific unit process must be made on the basis of the required removal efficiencies and the various side benefits, (i.e., other constituent removals) which they provide. The selection must also be based on the operating history and probable success of the unit process for its desired result and the operating difficulty or operating constraints associated with each.

The following discussion of each control category will present applicable data and discuss the reasons for initial process selection and any recent modification or changes.

PHOSPHOROUS REMOVAL

Phosphorous removal can be accomplished by any of four generally accepted treatment schemes:

1. Biological Phosphorous Removal
2. Biological-Chemical Phosphorous Removal
3. Selective Ion Exchange
4. Physical Chemical Phosphorous Removal

Biological Phosphorous Removal

Conventional biological wastewater treatment processes remove approximately 20% to 40% of incoming phosphorous. Some of this is incorporated into biological floc as it develops and is removed with the resulting solids. Phosphorous removal by activated sludge systems can be improved by promoting "luxury" uptake of phosphorous by biological organisms. Several demonstrations (3-5) have indicated up to 96% phosphorous removal. Problems associated with the variability and control of the process have led the DWD away from biological phosphorous control as the primary removal process.

Biological-Chemical Phosphorous Removal

Combination biological-chemical processes involve the direct injection of iron or aluminum salts (alum) into an activated sludge aeration tank. This technique has been studied by several investigators with resulting effluent phosphorous concentrations at around 1 mg/l. Flexibility of biological process operation is minimized when combining chemical coagulation and biological treatment within the same basin. Generally, however, the fluctuating and relatively low removal efficiency of this process led the Department away from the combination biological-chemical processes.

Selective Ion Exchange

Selective ion exchange through the use of activated alumina has been shown to provide excellent phosphorous removals. Culp and Ames (6) found up to 99% removals of phosphorous using granular media in columns. Other data indicated 90% removals. Shimp and Maxwell (7) found 0.01 mg/l effluent phosphorous concentrations in preliminary studies contacting granular activated alumina with filtered secondary effluent.

Selective ion exchange utilizing activated alumina was a strong contender as the phosphorous removal process in the Department's demonstration plant. However, the next process to be discussed provides additional benefits unobtainable through the use of activated alumina.

Physical-Chemical Phosphorous Removal

The physical-chemical process for phosphorous removal involves the use of lime, alum or iron salts for chemical coagulation of secondary effluent. Secondary effluent coagulation for phosphorous removal also provides nearly complete suspended solids removal prior to downstream process. Because the coagulation is done in basins separate from other processes, highly reliable and easily controllable operation results.

The influent wastewater quality is the factor which effects the quantity of chemical coagulant required to achieve a given degree of phosphorous removal. Alum, iron and lime requirements are affected by the alkalinity of the wastewater. Numerous plants utilizing lime precipitation clarification have provided valuable data assisting in the choice of the lime process for the Denver Water Department's demonstration plant.

Shah (8) evaluated lime precipitation and clarification at Denver's pilot plant. His data, graphed in Figure 3, indicated 95% removal efficiencies for total phosphorous at a lime dose of 250 mg/l $Ca(OH)_2$. This lime dose is relatively low because Shah used nitrified wastewater with an alkalinity of 100-125 mg/l as the influent to his process. This study further indicated nearly complete removal of coliform bacteria resulting from the adverse conditions of the pH 11 wastewater. The data also indicated removals of zinc, lead, chromium, manganese, copper, and iron somewhat independent of lime dose. At a lime dose of 275 mg/l, phosphorous concentrations in the process effluent were consistently less than 0.5 mg/l total phosphorous as P, with suspended solids, BOD and turbidity removals of greater than 97%.

In an effort to reduce the sludge produced in the lime process by reducing the lime dose and resulting pH to avoid $Mg(OH)_2$ precipitation, further studies were made on the effects of coagulant aids. Cavagnaro (9, 10) evaluated the benefits of adding ferric chloride as the coagulant aid to a lime precipitation system at the DWD pilot plant. These data showed that adding 12.0 mg/l of $FeCl_3$ following lime addition would significantly improve removal of particulate phosphorous. In pilot plant runs, total phosphorous residual was reduced to 0.7 mg/l as P with 180 mg/l of lime dosed. Runs without iron, required a lime dose of 360 mg/l to achieve a similar effluent concentration (note: wastewater alkalinity averaged 260 mg/l). Iron addition also improved suspended solids removal by 40% and reduced effluent turbidity to less than 5 JTU.

Alternatives to lime have also been studied in Denver. Fox (11) evaluated the use of alum followed by direct filtration at the pilot plant. At an alum dose of 110 mg/l, approximately 94% total phosphorous removal was achieved. This system showed trace metal removals for iron, manganese, chromium and lead.

Data obtained through operation of the Department's pilot plant have indicated that effective phosphorous removal can be achieved through relatively simple operation of a lime clarification system. The additional, or side benefits of this system also provide positive factors for its consideration. Lime treatment had been chosen in the conceptual design and will indeed be a demonstration plant process. Some modification will occur, however, from the original concept. This includes changing the two-stage lime recarbonation system originally proposed to a single-stage system. The reason for this modification is based primarily on experience at the Orange County Water Factory 21 and other plants where the second-stage system has provided little if any additional benefit to overall plant operation. The Department's demonstration plant will have the flexibility to operate in a two-stage mode by piping modification. It is, however, felt that single-stage treatment will likely provide the necessary results.

SUSPENDED SOLIDS REMOVAL

The relatively complete suspended solids removal necessary for potable reuse requires efficient filtration of the chemically coagulated effluent. The extremely efficient phosphorous removal requirements also dictate filtration for polishing. This process is also necessary to protect downstream units and to assure their efficient operation.

It is generally accepted that there are two methods of filtration:

1. Mechanical Filtration Devices
2. Granular Media Filters

Mechanical Filtration Devices

The Chicago Sanitary District (12) has conducted studies which indicate that microscreens are not suitable for filtration following chemical coagulation, as carried over floc particles shear and penetrate the filtering fabric. Experience at Denver's Marston Water Treatment Plant has also provided information which indicates the limitations of the microscreening technique.

Granular Media Filtration

Granular Media Filtration may involve single media operation where graded sand is utilized, or the operation may involve dual media typically utilizing anthracite and sand. An additional alternative is that of mixed media filtration utilizing anthracite, sand, and garnet. All of the various configurations have been used in both pilot and full-scale work involving treatment of secondary or advanced waste treatment effluents.

Mixed media filters were effectively used at South Lake Tahoe (13) to reduce both total phosphorous and suspended solids. Dual media filters are successfully used in many water treatment facilities following the coagulation process. As indicated previously, Fox (11) successfully demonstrated direct filtration of alum treated wastewater utilizing dual media filters at the Denver Water Department's Pilot Plant. In this study, filtration was accomplished at loading rates of 3-5 gpm/ft^2 with resulting filter run lengths of two to six hours. Five to six hour runs were produced at loading rates of 3 gpm/ft^2. While this system was designed to evaluate phosphorous removal, insight was gained into dual media filter operations with the future source water for the Denver Water Department's Potable Reuse Demonstration Plant.

Maxwell (14) studied various possibilities in order to optimize filter design for treating Denver's wastewater effluent. His study confirmed literature results which indicated that direct filtration of secondary effluent could produce good solids removals. Maxwell's data indicated that a dual media filter could provide 75% to 80% removal of turbidity and suspended solids at a loading rate of 6 gpm/ft^2 for run lengths of up to eleven hours. Data obtained during mixed media filtration runs on alum treated secondary effluent indicated 90% to 95% turbidity removals at a loading rate of 6 gpm/ft^2 for run lengths of three to four hours. Maxwell's data also indicated very little difference in the effectiveness of dual and mixed media filters for direct filtration of secondary effluent. When filtration followed precipitation, however, the mixed media produced somewhat higher removals than dual media.

McCampbell (15) examined the effects of alum and filter aid doses in Denver along with the effects of different loading rates on two types of filters. He found that at filter loading rates of 4 gpm/ft^2 or less, mixed media filters were superior. However, at higher loading rates, dual media filters became superior in terms of the amount of captured solids and overall capital costs. The addition of alum and polymer as filtration aids were found to optimize filtration of chemically pretreated waters. McCampbell summarized that the mixed media filter's superiority over a dual media filter appears to be limited to relatively low loading rates.

The demonstration plant will utilize dual media pressure filtration aided by the addition of alum and polymer. This is based on the most satisfactory results obtained through pilot plant operations as well as operating history at numerous plants throughout the country.

NITROGEN REMOVAL

The four most effective treatment processes for nitrogen removal include:

1. Biological Nitrogen Removal
2. Breakpoint Chlorination
3. Ammonia Stripping
4. Selective Ion Exchange

Biological Nitrogen Removal

The biological nitrogen removal processes involve the oxidation of nitrogenous compounds to nitrates by maintaining an aerobic environment in a biological treatment system. The nitrates, thus formed, may be reduced to nitrogen gas in a separate biological treatment system operated under anoxic conditions. The oxidation step in this process is referred to as nitrification while the reduction step is denitrification. Successful studies (16-18) utilizing nitrification and denitrification have been conducted over the past few years. The simplicity of the structures needed for the process and the fact that nitrogen gas is the discharge makes the process one for strong consideration. The variability in process performance, however, as noted at other pilot plants, and the difficulty in recovering process efficiency following biological upsets (19) are major points of concern in considering the application of the process in the Denver operation. Another negative factor is the cold climate of the Denver area and the negative effect that low temperature has on the biological nitrification-denitrification process.

Koltunick (20) evaluated biological nitrification of secondary wastewater by activated sludge at the Denver Water Department's Pilot Plant. At mixed liquor suspended solids levels of 2000 mg/l, he found that a two-hour detention period produced an effluent with no ammonia present. Lower temperature and lower mixed liquor suspended solids resulted in lower efficiency. In his studies typical BOD_5/TKN ratios of 2.7 were observed. Data obtained from his operation led to the development of the family of curves in Figure 4. Continued resceding was necessary, however, because of operation problems and shock loading. While the process showed promising results, operational problems left concern regarding the reliability of this biological process for nitrogen control. Problems observed in the nitrification process may have been partially caused by the small scale pilot facilities in which the process was evaluated.

Breakpoint Chlorination

Breakpoint chlorination provides efficient and assured nitrogen control, although at relatively greater cost than the biological alternatives. The process has been successfully used in numerous pilot studies and full-scale operations including South Lake Tahoe and Water Factory 21.

Swanson (21) evaluated nitrogen removal from wastewater by breakpoint chlorination at the Department's pilot plant. Varying chlorine to nitrogen ratios on different pretreatment effluents reduced ammonia 90% to 99% while organic nitrogen was reduced 0 to 60%. Breakpoint chlorination followed by activated carbon contact proved to be a very efficient ammonia removal process consistently averaging greater than 99% ammonia removals, regardless of pretreatment techniques. It appeared that activated carbon performed three functions as a post breakpoint chlorination process: these were the catalyzation of the breakpoint reaction, nitrate removal, and dechlorination. In general the chlorine to ammonia nitrogen ratio ranged from 8 to 10.5:1 depending on the pretreatment characteristics of the wastewater. This study indicated that strict control of chlorine dose to exactly the breakpoint and strict pH control were required to achieve maximum efficiency.

Because of the substantial operating costs associated with high chlorine doses and high ammonia concentrations, several applications have used breakpoint chlorination as a polishing technique with another nitrogen removal process doing the lion's share of removal.

The principal disadvantages of breakpoint chlorination are the large increase in TDS and the high operating costs. Additionally, because of current concerns for chlorinated organics and the potential for breakpoint chlorination to form these compounds, other alternatives are warranted.

Ammonia Stripping

The ammonia stripping process for the removal of nitrogen has been used on a plant scale at both South Lake Tahoe and Water Factory 21. At these plant sites the process has shown promise for removal of ammonia from wastewater under favorable temperature conditions. The major restriction of the process for application to the Denver Project is the climate and the temperature dependence of the process. Experience at South Lake Tahoe has indicated unsatisfactory results during winter time operation which include low removal efficiency and system freezeup. At both South Lake Tahoe and Water Factory 21, additional facilities for ammonia polishing utilizing breakpoint chlorination, are designed into the system. Because of the problems associated with climate, ammonia stripping was not considered for the Denver Project.

Selective Ion Exchange

The selective ion exchange process utilizes zeolites which are selective for ammonia relative to calcium, magnesium and sodium. The currently favored zeolite is clinoptilolite, which naturally occurs in several extensive deposits in the United States. Several studies of the process have been conducted as well as the design and construction of two full-scale operating plants at the Tahoe-Truckee Sanitation Agency and Occoquan.

Pilot and full-scale operations indicate average ammonia removals of 96% when influent ammonia nitrogen concentrations were approximately 20 mg/l. A study currently underway at the Department's pilot plant by Jelnick (22) has indicated a reduction in NH_3-N from 17.2 mg/l to a level of 1.00 mg/l at a 200 bed volume throughput. Neutral pH regeneration requires 22.5 bed volumes of 2% NaCl. The study is continuing to evaluate high pH regeneration and compare various zeolite sources. Because of its reliability and the ease of process control, selective ion exchange emplcying clinoptilolite has been chosen as the primary process for ammonia removal for the demonstration plant.

In an effort to effect complete removal of ammonia nitrogen, breakpoint chlorination had been considered as a backup and polishing step for Denver's clinoptilolite system. Since the initial conceptual design, however, major concerns associated with chlorinated organics and other chlorine oxidation products provoked a decision to remove breakpoint chlorination as a process in the demonstration plant. Therefore, the nitrogen removal will rely on clinoptilolite with polishing accomplished by other processes discussed below.

SOLUBLE ORGANIC REMOVAL

The adsorption or chemical oxidation processes that may have application to remove the residual refractory organics from wastewater include:

1. Granular Activated Carbon
2. Powdered Activated Carbon
3. Polymeric Adsorption
4. Ozonation
5. Catalytic Oxidation

Comparative data from various organic removal processes can be seen in Figure 5.

Granular Activated Carbon

The use of granular activated carbon (GAC) for removal of refractory organic material from wastewater has been clearly demonstrated as an efficient, reliable and economical unit process on a plant scale at South Lake Tahoe, Water Factory 21, Pamona, Colorado Springs, and several other plants around the country. The regeneration of the carbon in multiple hearth and other types of furnaces has been perfected with nearly complete recovery of the adsorptive capacity of the carbon while minimizing carbon losses. The technology associated with applying carbon for wastewater treatment processes is well known and has been described in great detail.(23) Numerous studies at the Department's pilot plant have indirectly involved the evaluation of granular activated carbon as a treatment process either preceding or following any of several other unit processes. Swanson (21) followed his breakpoint chlorination system with granular activated carbon and observed relatively high removal efficiencies with respect to COD. Typical effluent concentrations ranged down to 5 mg/l of COD. Panswad (24) applied granular activated carbon following his ion exchange system and observed average COD removals of 80%. Typical contact times in both studies were 30 minutes. McLaughlin (25) and Bomberger (26) in their studies involving reverse osmosis employed granular activated carbon as a pretreatment process. Both studies utilized a carbon contacting time of 33 minutes at a loading rate of 2.3 gpm/ft^2. In both cases COD removal efficiencies of 75%, resulting in effluent concentrations of 10 mg/l COD were consistently observed.

Mann (27) evaluated granular activated carbon and various pretreatment systems at the DWD pilot plant. The data indicated very little effect of pretreatment on the rate of organic removal. Most of the COD had been removed within 20 minutes of contact. At a contact time of 30 minutes, 70% to 83% COD removals were observed independent of pretreatment. Lime and alum pretreatment, however, did reduce the COD in the product from 13 mg/l without chemical pretreatment to 5-10 mg/l with chemical addition. Granular activated carbon had been chosen for the organic removal process and will be used for organic removal in the demonstration plant.

Powdered Activated Carbon

Powdered activated carbon provides a very efficient removal of soluble organic materials. The extremely small carbon particle size provides very high removal rates so that efficient organic removal can be provided at short contact times. A major problem associated with the use of powdered activated carbon is the recovery and reuse of the carbon. Recently, the fluidized bed regeneration and wet air oxidation techniques for powdered activated carbon have made the process somewhat more feasible for application. Other problems associated with powdered activated carbon include severe dusting and the difficulty of separating and recovering the carbon from the wastewater system.

Rothberg (28) evaluated powdered activated carbon as a tertiary treatment process for organic removal at the DWD pilot plant. The study determined that several powdered activated carbons were effective in treating the applied wastewater and were capable of reducing chemical oxygen demand by up to 90% at rather high dose levels. Problems associated with carbon recovery from the wastewater system were observed in this study and led to the evaluation of a lime-powdered carbon system. Powdered activated carbon contacting and settling was followed by a high lime treatment process. A single stage process dosing 400 mg/l PAC followed by 300 mg/l of $Ca(OH)_2$ resulted in COD removals of 87% and suspended solids removals of 86% to 3 mg/l. Significant removals of copper, iron, lead, manganese, zinc, chromium, strontium, total and fecal coliform and total phosphorous were observed in the system. Effluent COD concentrations ranged to less than 5 mg/l. While carbon carry over was still a problem, the system employing high lime precipitation offered some promise. The problems in handling the dry powdered activated carbon as well as carbon recovery were a factor in the dismissal of this process for the Denver Plant.

Polymeric Adsorption

Certain synthetic adsorbents consisting of polymeric resins developed for analytical determinations of trace organics and other adsorptive functions have been considered for organic removal. This adsorbent method shows potential as a possible alternative to carbon adsorption particularly for trace organic removals. However, insufficient data with regard to pilot work and the prevailing economic and operational problems indicate that this method is not currently suitable for full-scale operation.

Panswad (24) evaluated ion exchange for both organic and inorganic removals in the Department's pilot facility. While this study did not employ polymeric adsorption resins, anionic and cationic ion exchange resins were evaluated for organic removal. The study indicated that organic matter was adsorbed onto the anionic resin by a combination of physical and chemical mechanisms. COD removal averaged from 50% to 60% within the ion exchange system. The relatively high organic removals were still achieved following regeneration, although some deterioration in efficiencies was noticed as operation cycles continued.

Ozone

Ozone has been used for the disinfection of water supplies for many years, particularly in Europe. Ozone has the advantage of being an extremely potent germicide, even against organisms such as virus and cysts, it also has the ability to oxidize many organic compounds and imparts extremely high dissolved oxygen concentrations to the water. The oxidation of COD by ozone has been observed by several studies including pilot work at Blue Plains (29). The value of ozone as a primary oxidant for reduction of organics is questionable, however, because of effects associated with the kinetics of the ozone reaction and the fact that reaction rates slow considerably after 50% reduction in COD's. The promise of ozone as a polishing oxidant for low concentrations of organics led to its initial inclusion in the demonstration plant conceptual design as an oxidation step following the demineralization process.

Current work underway at the Department's pilot plant by Schmaus (30) has indicated limited effectiveness of ozone for reduction of COD in lime treated filtered secondary effluent. The data does indicate the effectiveness of ozone as a disinfectant, however. The portion of the study currently in progress is utilizing ozone in combination with granular activated carbon and shows uncertain performance in initial short term runs. Increases in dose or ozone contact time has little effect on removal efficiencies. Ozone added as an oxidant following activated carbon has had little effect at doses up to 44.5 mg/l for contact times up to 20 minutes.

Catalytic Oxidation

There are several potential combinations of oxidants and catalysts for soluble organic removal. The concept is to provide a catalyst which will improve the oxidation kinetics for refractory organics. Catalysts ranging from iron salts to high frequency sound and ultraviolet light have been utilized for catalytic oxidation reactions. Ultraviolet light (UV) catalyzed ozonation is a process receiving a good deal of attention currently. The U.S. Army Medical Research & Development Command is including UV-ozone for refractory organic removal in the mobile field hospital unit. The possibility had originally been considered of utilizing UV catalyzed ozone as the final oxidation step in the Department's Demonstration Plant. Because of concern over the products of any oxidant reaction, however, the ozone or UV catalyzed ozone oxidation process will be removed from the proposed plant flow stream.

The treatment system now proposed will be modified, to provide the ability to add ozone between first and second stage carbon contact. Recent data concerning biologically activated or ozone enhanced carbon shows promise from the standpoint of both organic and residual ammonia control. The biological growth in the carbon columns assisted by high dissolved oxygen concentrations developed by ozonation can effectively nitrify any residual ammonia leaking past the clinoptilolite exchangers.

The lower concentrations of ozone typically necessary for biologically enhanced carbon should not cause significant problems with oxidation products as opposed to the concerns expressed over the high doses necessary for ozone oxidation or UV catalyzed ozone oxidation.

DEMINERALIZATION

There are five different methods often proposed for demineralization of water:

1. Freezing
2. Distillation
3. Electrodialysis
4. Ion Exchange
5. Reverse Osmosis

Comparative data from the various demineralization processes can be seen in Figure 8.

It is generally felt that those methods requiring a phase change such as freezing and distillation are most suitable for sea water or other high TDS concentration waters.

Freezing

While freezing was initially considered a possibility in the Department's Demonstration Plant, the economics of the process and the limited data available indicate impracticality for low salinity waters such as municipal wastewater and as such was dismissed from further consideration.

Distillation

Distillation involves the boiling of a saline solution to remove the water phase from the relatively non-volatile organics and dissolved salts. Burrell (31) evaluated distillation as an advanced waste treatment method for Denver wastewater. His study indicated that distillation has some promise as an AWT technique. His study found, however, that if ammonia and volatile organics are present in the plant feed, they carry over and foul the plant product. Effluent TDS concentrations of 50 mg/l are obtainable utilizing various distillation techniques, however, costs are expected to be relatively high.

Ablondi (32) performed experiments utilizing Denver Metro Secondary Effluent and operated both batch and continuous reactors of both conventional and multi-stage type. While successful results occurred with respect to TDS concentrations, problems were again observed with both ammonia and organic carry over. Extensive odor problems were also noted. While GAC following distillation was relatively successful in removing both the odors and organics, problems still persisted with ammonia.

Energy requirements for the distillation of wastewater are rather intensive and combined with the other disadvantages of the process, it has been given no further consideration for use in the Demonstration Plant.

Electrodialysis

The electrodialysis process is well developed and has been used for the treatment of brackish water supplies. Electrodialysis desalts by causing the migration of ions through selectively permeable membranes under the influence of direct current. Major pilot studies on the treatment of municipal wastewater have been conducted at several sites around the country. The process has both advantages and disadvantages similar to those associated with reverse osmosis. The technology is well developed and some removal of most inorganic constituents is realized. The removal efficiency, however, is directly proportional to the amount of current and as removal requirements increase, power costs increase also. The process is also affected by temperature with lower temperatures decreasing efficiency.

Ion Exchange

The ion exchange process has been extensively used in industry for process water treatment. High pressure boiler water operations require near complete removals of minerals which are successfully met by ion exchange processes. Many laboratory and pilot studies have utilized ion exchange to demineralize wastewater. Panswad (24) evaluated ion exchange as a demineralization technique at the Department's pilot plant. His study evaluated two anionic resins along with a weak acid and strong acid cationic exchanger in different combinations. His various systems were capable of removing all sulfate ions, about 83% of the chloride ions, and 95% of the orthophosphate, over a 200 bed volume throughput. Surface loading rates of 3.3 gpm/ft^2 with 22 minute contact time were able to remove 90% of the total dissolved solids. Regeneration involved 5 pounds of H_2SO_4/ft^3 of resin in the cationic exchangers. The anionic exchangers required 3 to 4 pounds $NaOH/ft^3$. In combination with the favorable organic removals discussed previously, the ion exchange system would provide a satisfactory demineralization method for the Department's Demonstration Plant.

While the ion exchange process showed promise, the side benefits of the next process to be discussed were a major factor in choosing it over ion exchange.

Reverse Osmosis

Reverse osmosis is the newest of the salt removal processes and has been extensively developed during the past few years for treatment of both brackish waters and wastewaters. There have been many pilot plant and demonstration studies on reverse osmosis for municipal wastewater demineralization. Most recently, Water Factory 21 has installed a 5 MGD reverse osmosis demineralization plant.

The Denver Water Department has conducted pilot studies utilizing spiral-wound membranes of both cellulose acetate and polyamid materials from two manufacturers. McLaughlin (25) evaluated one manufacturer's membranes comparatively for their rejection of wastewater constituents under various pretreatment conditions. The removal data for the several constituents evaluated can be seen in Figures 6 and 7 and is rather impressive for both the cellulose acetate and polyamid membranes. It can be seen by comparing Figures 6 and 7 that as pretreatment decreases, effluent concentrations of the various parameters increase slightly, however, the COD, ammonia nitrogen, and TKN are less than 1 mg/l and the nitrate and nitrite nitrogen are less than 0.05 mg/l. The polyamid membrane with only filtration of secondary effluent as pretreatment provided the lowest TDS concentrations, ranging to 34 mg/l while the cellulose acetate ranged to 135 mg/l. Bomberger (26) found similar results when evaluating pretreatment and comparing both cellulose acetate and polyamid membranes from two different manufacturers.

Advantages of the reverse osmosis process include the fact that the process generally provides a physical barrier to the passage of material. The process shows consistently high removals of organics, turbidity, bacteria, and virus as well as inorganic material. Removal efficiencies and power consumption remain relatively stable over a wide range of TDS concentrations present in the feed water. The disadvantages of the reverse osmosis process include the negative effects of scaling and the susceptibility of the system to damage from improper operation. These can be mitigated, however, and the Denver Water Department has chosen the reverse osmosis process as the demineralization step for the Demonstration Plant.

DISINFECTION

Complete and total disinfection is necessary for the successful operation of the demonstration plant. The various methods of disinfection available involve use of strong oxidants and include:

1. Chlorine
2. Chlorine Dioxide
3. Ozone
4. Ultraviolet Light

Chlorine

The effectiveness of chlorine as a disinfectant is debatable. Numerous studies have indicated varying contact times and dose requirements for disinfection of organisms ranging from indicator bacteria to virus and cysts. The advantages of chlorine as a disinfectant are its ease of application and the detailed information known about its use. The disadvantages are the byproducts formed when chlorine oxidizes various organic chemicals.

Chlorine Dioxide

Chlorine dioxide has shown favor as a disinfectant in the last few years. EPA has conducted several studies (33) utilizing the compound as a disinfectant for water and wastewater. The careful control of chlorine dioxide disinfection reduces the potential for formation of chlorinated organics. Chlorine dioxide must be generated on site and is usually the product of a reaction of chlorine gas with sodium chlorite. Because of the extremely rapid kinetics of chlorine dioxide reactions, it is necessary to rapidly disperse it into the wastewater and to provide intimate contact for complete disinfection.

Ozone

As previously discussed, ozone is a very strong oxidant and has been shown from various studies to be an effective bactericide. It has also shown its effectiveness against virus and cysts. Schmaus (30) has found nearly complete removals of Total Coliforms when applying 15 mg/l ozone for contact periods of 6 minutes and similar removals at 10 mg/l doses for 10 minutes of contact. Questions concerning the formation of oxidation byproducts with ozone are currently under investigation.

Ultraviolet Light

Ultraviolet light also has capability for disinfection purposes. The problems associated with ultraviolet disinfection involve the passage of the light through water. Relatively clear solutions are necessary to insure proper disinfection, and design of the UV system must be such that the water passes over the UV source in thin sheets. At large scales, these design constraints cause severe problems.

Chlorine was originally chosen as the disinfectant for the demonstration plant. Because of concern over chlorinated organics and oxidative byproducts, however, the disinfection process has been changed from chlorine to chlorine dioxide. Since the feed water for the demonstration plant will be unchlorinated secondary effluent from the Metro treatment plant, there will be no chlorine added at any point in the system.

REVISED TREATMENT TRAIN

Relying on the data acquired through recent operations of both pilot and full-scale facilities as well as the concerns regarding harmful products in water, the Denver

Water Department and the U.S. Environmental Protection Agency have agreed upon the treatment train and the various modifications previously discussed. This revised process train for the demonstration plant is shown in Figure 9. Based on literature, design experience, and pilot plant data, the design summary for the demonstration plant can be seen in Figures 10-14. Phosphorous removal will be accomplished by high lime precipitation utilizing single stage recarbonation. The side benefits of this process are removals of turbidity, disinfection, viral inactivation, suspended solids removal, some softening, and some heavy metals removal.

The primary suspended solids removal process will be chemically aided dual media pressure filtration which can provide additional benefits of bacterial and virus removals, and additional reductions in phosphorous.

The primary nitrogen removal process will utilize clinoptilolite for the selective ion exchange of ammonia. The process will provide additional filtration.

The soluble organic removal process will utilize granular activated carbon enhanced by ozone between the first and second carbon stage. The process will provide additional removals of virus and bacteria, heavy metals and oxidation of residual ammonia nitrogen to nitrate.

The demineralization process will utilize reverse osmosis. This process will provide additional removals of bacteria and virus, trace metals, soluble organics, and ammonia and nitrate nitrogen.

The disinfection process will involve the on site generation and addition of chlorine dioxide and should provide final and residual disinfection of the product water.

The design of this plant will be complete in May, 1980, followed by a two-year construction period. Following construction, a start up and shake down period of six months will determine process operation characteristics and will be followed by 4½ years of "normal" operation. During the operation period, the product water will be subjected to an extensive analytical testing program and to a health effects research program which will involve evaluation of accute and genetic toxicity and both subchronic and chronic testing on both sexes of two species of warm-blooded animals.

The overall costs of this project are currently estimated at $21.6 million. The Denver Water Department is entering into a cooperative agreement with the U.S. Environmental Protection Agency which will provide $7 million of federal funds for this project. The demonstration program is developed to provide the necessary information to determine if potable water can, in fact, be produced directly from secondary effluent. If this program proves successful, as the Denver Water Department fully expects it will, Denver will be on its way toward the implementation of a full-scale, 100 MGD reuse program which could provide up to 15% of Denver's municipal water supply by the year 2000.

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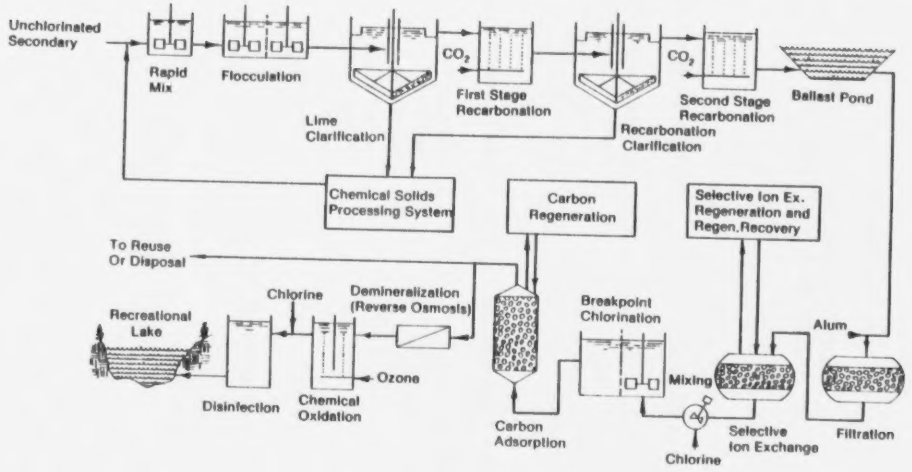
1975

Conceptual Design

Process Flow Diagram - Proposed Denver Plant



(After CH_2M - Hill 1975)[2]

Figure 1

Figure 2

REMOVAL OPERATIONS AND UNIT PROCESS OPTIONS

Phosphorous Removal

- Biological Phosphorous Removal
- Biological-Chemical
- Selective Ion Exchange
- Physical-Chemical

Suspended Solids Removal

- Mechanical Filtration
- Granular Media Filtration

Nitrogen Removal

- Biological Nitrogen Removal
- Breakpoint Chlorination
- Ammonia Stripping
- Selective Ion Exchange

Soluble Organic Removal

- Granular Activated Carbon
- Powdered Activated Carbon
- Polymeric Adsorption
- Ozonation
- Catalytic Oxidation

Total Dissolved Salts Removal

- Freezing
- Distillation
- Electrodialysis
- Ion Exchange
- Reverse Osmosis

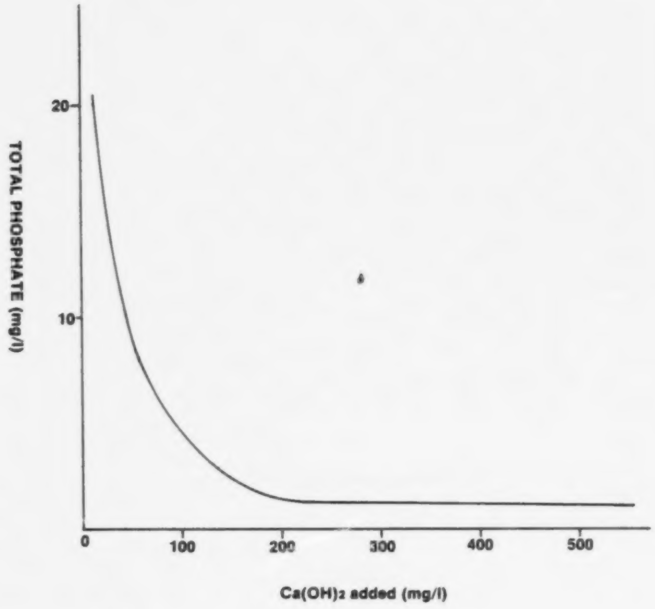
Disinfection

- Chlorine
- Chlorine Dioxide
- Ozone
- Ultraviolet Light

Figure 3

TOTAL PHOSPHATE AFTER LIME TREATMENT AS A FUNCTION OF LIME DOSE

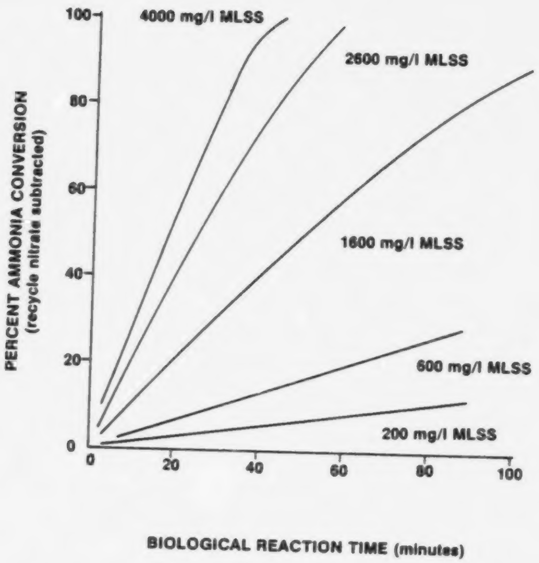
Influent PO_4 ranged from 12 to 48 mg/l



Denver Pilot Plant Studies after Linstedt and Bennett (1973)

Figure 4

EXTENT OF BIOLOGICAL NITRIFICATION AS A FUNCTION OF REACTION TIME



Denver Pilot Plant Data after Linstedt and Bennett (1973)

Figure 5

SUMMARY OF ORGANIC REMOVAL PROCESSES

Process	Demonstrated COD Removal Data		Comments
	Average Effluent	Average % Removals	
Granular Activated Carbon			A proven organic removal process
DWD Pilot Studies			
1. Secondary Effluent	—	75	
2. Lime Effluent	—	83	
3. Bio-Nitrification-Lime	—	68	
4. Lime-Filter (Virgin Carbon)	2.5 mg/l	94	
Powdered Activated Carbon			Severe problems in carbon solids removal
DWD Pilot Study			
1. Secondary Effluent Two Stage Counter Current Contactor *PAC Doses Ranging 150-600 mg/l*	3.8-18.56 mg/l	53-91	
2. Secondary Effluent Single Stage Contactor *PAC Doses Ranging 200-600 mg/l*	7.09-18.49 mg/l	54-77	
3. Secondary Effluent PAC-Lime *PAC Doses Ranging 250-600 mg/l*	8.5-14.1 mg/l	74-88	
Ion Exchange			
DWD Pilot Study			
1. Alum-WAC-SAC-WBA	9.2 mg/l	67	
Ozone			
1. Lime-Filter-Carbon (Virgin)	4-6 mg/l	—	Preformance uncertain
2. Lime-Filter-Ozone-Carbon (Virgin)	1-5 mg/l	—	Preformance uncertain

Figure 6

PILOT REVERSE OSMOSIS DATA

Parameter (Concentration in mg/l)	Filtration					
	Cellulose Acetate			Polyamid		
	Inf	Eff	Removal %	Inf	Eff	Removal %
COD	43.7	0.68	98.43	37.9	0.09	99.74
NH_4^+	12.1	0.85	92.97	15.0	0.90	93.98
NO_2^-	0.028	0.005	80.98	0.06	0.008	86.38
NO_3^-	0.01	0.	99.	0.08	0.	99.
TKN	28.0	0.84	96.98	24.0	0.86	96.42
Total-$P0_4^{\equiv}$	—	0.019	—	2.85	0.014	99.50
Ortho-$P0_4^{\equiv}$	—	0.012	—	2.65	0.009	99.67
Hardness	170	0.	100	150	0.	≈ 100
Alkalinity	40.1	10.79	73.10	42	3.25	99.27
Total Solids	528	106.4	79.80	492	29.13	94.07
Conductivity (μmho/cm)	1050	45.6	95.65	870	34.36	96.05

After McLaughlin 1979

Figure 7

PILOT REVERSE OSMOSIS DATA

Parameter		Lime-Filtration-Carbon				
	Cellulose Acetate			Polyamid		
(Concentration in mg/l)	Inf	Eff	Removal %	Inf	Eff	Removal %
COD	2.4	0.	99.	2.5	0.35	85.8
NH_4^+	12.0	0.63	94.76	11.0	0.87	92.0
NO_2^-	0.3	0.07	75.4	0.27	0.04	85.6
NO_3^-	0.75	0.24	68.3	0.35	0.05	85.7
TKN	13.90	0.84	93.9	13.3	0.81	93.9
Total-$PO_4^{\equiv}$	0.56	0.02	96.4	0.9	0.05	94.0
Ortho-$PO_4^{\equiv}$	0.32	0.003	98.7	0.2	0.0	≈ 100
Hardness	290	0.	100	136.0	.95	99.29
Alkalinity	26.6	0.	100	34.6	5.53	83.99
Total Solids	1070	30.17	97.18	867	48.8	94.37
Conductivity (umho/cm)	1000	30.36	96.9	880	43.6	95.04

After McLaughlin 1979

Figure 8

SUMMARY OF DEMINERALIZATION PROCESSES

Process	Parameter	Demonstrated Removals	
		Eff	Removal %
Ion Exchange DWD Pilot Plant Lime-Carbon-SAC-WBA	TDS	35 mg/l	94
	Hardness ($CaCO_3$)	2.0 mg/l	99
Distillation DWD Pilot Plant 3 Effect Evap	Conductivity	100 μmho/cm	90
Reverse Osmosis DWD Pilot Data Lime-Filter-Carbon Polyamid	TDS	5.0 mg/l	99
	Conductivity	43 μmho/cm	95
Lime-Filter-Carbon Cellulose Acetate	TDS	131 mg/l	86
	Conductivity	30 μmho/cm	97
Filter Polyamid	TDS	29 mg/l	94
	Conductivity	34 μmho/cm	96
Filter Cellulose Acetate	TDS	106 mg/l	80
	Conductivity	45 μmho/cm	96

1979

Revised

Process Flow Diagram - Proposed Denver Plant

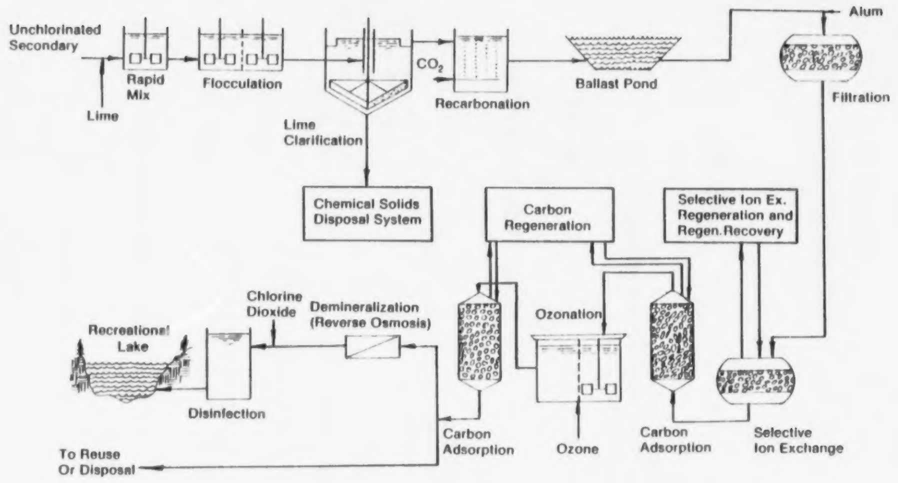


Figure 9

Figure 10

DESIGN SUMMARY
1

RAPID MIX

BASINS	
NUMBER	2
NUMBER NORMALLY IN SERVICE	2
DIMENSIONS	5′ x 5′ x 5′ SWD
VOLUME	125 CF
MIXING TIME	2.2 MIN.

LIME FLOCCULATION

BASINS	
NUMBER	2
NUMBER NORMALLY IN SEVICE	2
DIMENSIONS	5′ x 16′ x 10′ SWD EACH BASIN 5′ x 8′ x 10′ SWD EACH STAGE
VOLUME	800 CF EACH BASIN 400 CF EACH STAGE
FLOCCULATION TIME	14.1 MIN.
FIRST STAGE FLOCCULATOR VELOCITY GRADIENT	135 FPS/FT
SECOND STAGE FLOCCULATOR VELOCITY GRADIENT	60 FPS/FT

LIME CLARIFIERS

CLARIFIERS	
NUMBER	2
NUMBER NORMALLY IN SERVICE	2
SURFACE AREA	1400 SF
LOADING WITH TWO IN SERVICE	864 GPD/SF
SLUDGE FLOW FROM CLARIFIERS	68 GPM (@ 1 PERCENT SOLIDS)

Figure 11

DESIGN SUMMARY
2

RECARBONATION BASINS

BASIN	
NUMBER	2
NUMBER NORMALLY IN SERVICE	2
DIMENSIONS	6′ x 6′ x 14′ SWD
VOLUME	504 CF
DETENTION TIME	9.6 MINUTES

BALLAST POND

PONDS	
NUMBER	2
DIMENSIONS, EACH	80′ x 40′ x 9′ SWD
VOLUME, EACH	215,000 GALLONS
DETENTION TIME	8.4 HRS WITH TWO IN SERVICE

PRESSURE FILTERS

FILTERS	
NUMBER	3
NUMBER NORMALLY IN SERVICE	2
NUMBER NORMALLY BEING BACKWASHED	1
DIMENSIONS	8′ DIAMETER BY 10′ LONG
NOMINAL FILTRATION RATE	5 GPM/SF
NET FILTRATION RATE	4.83 GPM/SF
MEDIA DEPTH	36 IN.

Figure 12

DESIGN SUMMARY
3

SELECTIVE ION EXCHANGE

EXCHANGE BEDS	3
NUMBER	3
NUMBER NORMALLY IN SERVICE	2
DIMENSIONS	10' DIAMETER BY 12' LONG
DEPTH OF MEDIA	4'
TYPE OF MEDIA	CLINOPTILOLITE
VOLUME OF EACH BED	3,500 GALLONS
LOADING RATE, VOLUME	6.6 BV/HR
LOADING RATE, SURFACE	3.3 GPM/SF
BACKWASH RATE	8 GPM/SF

ACTIVATED CARBON ADSORPTION

COLUMNS	
TYPE	UPFLOW/DOWNFLOW
NUMBER	2 OR 3
NUMBER NORMALLY IN SERVICE,	
SINGLE-STAGE	1
TWO-STAGE	2
DIMENSIONS	12' DIAMETER BY 24' CARBON DEPTH
EFFECTIVE CARBON VOLUME	2,710 CF/COLUMN
TOTAL CARBON WEIGHT	70,500 LB/COLUMN
CARBON SIZE	8 x 30 MESH
DESIGN SURFACE LOADING RATE	6.7 GPM/SF
DESIGN PSEUDO CONTACT TIME	
SINGLE-STAGE OPERATION	26.8 MINUTES
TWO-STAGE OPERATION	53.6 MINUTES
DESIGN UPWASH RATE	15 GPM/SF

Figure 13

DESIGN SUMMARY
4

DEMINERALIZATION

DEMINERALIZATION METHOD	REVERSE OSMOSIS
TYPE OF MODULE	SPIRAL WOUND
SIZE OF MODULE	4 IN. DIAMETER
PERMEATE CAPACITY OF MODULE, EACH	1,000 GPD @ 60°-75° F.
NUMBER OF MODULES PROVIDED	126
NUMBER OF MODULES PER PRESSURE VESSEL	6
PRESSURE VESSEL CONFIGURATION	12-6-3 ARRAY
WATER RECOVERY	70-85 PERCENT
NORMAL OPERATING PRESSURE	400 PSIG
MAXIMUM OPERATING PRESSURE	600 PSIG

DISINFECTION

CHLORINE DIOXIDE CONTACT BASIN	
NUMBER	1
DIMENSIONS	5' x 10' x 6' SWD
VOLUME	300 CF
DETENTION TIME	34 MINUTES

GROUNDWATER RECHARGE AT WATER FACTORY 21

Neil M. Cline
Secretary Manager
Orange County Water District

GENERAL

In 1956 the population of the Orange County Water District within Orange County, California was 500,000 persons. The annual water requirement was 232,000 acre-feet of which 123,000 acre-feet, 53 percent, were used for irrigation and 109,000 acre-feet, 47 percent, for municipal and industrial purposes. The County was in the midst of a growth boom that had proceeded unabated following World War II. To support the postwar expansion the community was relying to a large extent upon groundwater, which resulted in a serious overdraft of groundwater supply. The Orange County Water District, organized in 1933 to protect local interests in the Santa Ana River and manage the area's groundwater, reported seawater had intruded as much as 3-1/2 miles inland.

In 1979 the population of OCWD is nearing 1.5 million people. The annual water requirement is 400,000 acre-feet, of which 50,000 acre-feet, 12 percent, is applied for irrigation and 350,000 acre-feet, 88 percent, for municipal and industrial consumption. Groundwater remains the principal source of water supply for the burgeoning community, however. Even though the demand for water far exceeds the safe yield of the local watershed there is every reason to believe that groundwater resources will continue as the backbone of local water supply.

The District, with the support of local water users and in cooperation with the Metropolitan Water District of Southern California (MWD), has developed management procedures that will perpetuate groundwater reliability.

For the last 60 years Southern Californians have been pursuing programs to supplement local water supply by importing additional water. The first major import system to be developed was the Owens Valley Aqueduct, contracted by the City of Los Angeles in 1913. In the 1920's MWD was organized to transport Colorado River water to the South Coastal plain, and in 1960 MWD contracted with the State of California for additional water to be transferred from Northern California via the California aqueduct. Orange County was among the original MWD members, and presently is utilizing groundwater accumulated as a consequence of flow from the Santa Ana River and local drainage, Colorado River water and Northern California water. Since 1949 Orange County Water District has been importing large amounts of Colorado River water for groundwater recharge to supplement Santa Ana River flows. To date more than 2.2 million acre-feet of imported water have been percolated into the area's groundwater reserve for use to meet increasing demand and to repel saline intrusion.

It has been apparent for some time that to sustain an adequate water supply for Orange County's expanding economy additional supplementary sources must be established.

The historic interbasin transfer of water supply has never been unanimously supported. MWD has constructed and operates the Colorado River aqueduct designed to furnish 1.2 million acre-feet per year, and has contracted with the State of California for 2.0 million acre-feet of Northern California water. Both of these massive import programs have been accomplished in spite of enormous opposition from the areas of origin. The Colorado River supply was in court for 36 years and was finally settled in 1964, 15 years after the completion of the aqueduct, in Arizona's favor. By 1985 California will lose more than half the volume it is currently diverting from the Colorado River. The Northern California waters have not been subject to such heavy litigation, but the philosophy of transferring several million acre-feet from north to south has been the subject of heated debate since the 1920's when the idea was first considered by California's water planners. The voters of the State approved a bond issue in 1960 to construct the State Water Project to develop water storage and Statewide transfer systems, but significantly the key element to the efficiency of the State Project, a canal system linking the Sacramento River to the State aqueduct, has never been completed due to local opposition and Statewide environmental protection concerns.

The construction of this unit, the Peripheral Canal, has been and continues to be the biggest single resource issue in the State. The current, and perhaps chronic, energy shortage adds to the difficulties of importing additional water. It is not surprising therefore that in Southern California it is anticipated that, in part, the area's future water requirements will be satisfied through increased water conservation and wastewater reclamation programs. The region's water supplies will ultimately be composed of fully developed local resources, conjunctively used with a combination of imported Northern California and Colorado River water, reclaimed wastewater and limited desalted brackish supply.

In the expectation of what is now occurring, the Orange County Water District has developed a wastewater reclamation system to provide a source of supply to hydraulically prevent seawater intrusion into the area's invaluable groundwater reserve. Figure 1 is a location map of Orange County and the Water District boundary.

SEAWATER INTRUSION PROBLEM

The Orange County groundwater basin is the depositional plain of the Santa Ana River. The principal features of the region are surrounding hills and a broad poorly drained alluvial plain with alternating gaps and minor hill systems along the coast. A major fault system somewhat parallels the coastline, which, as far as has been determined, seals the basin from the sea at deeper levels. However, in several gaps along the ocean front there is hydraulic continuity between seawater and groundwater in the upper 150-200 feet of recent alluvial fill.

In general, the aquifers of the area are composed of fine- to coarse-grained sand, separated by silt and clay aquicludes. The Talbert aquifer, the principal zone of production in the area, is Recent age and uncomformably overlies the Pleistocene deposits within the gap created by the Santa Ana River. The Talbert is the only aquifer in direct contact with the ocean. The lower three zones of local production are subject to intrusion by virtue of their contact with the Talbert.

Figure 2 is a general cross section of the groundwater basin. In mid-County it is over 4,000 feet to the base of the fresh water bearing sediments. The fresh water base rises to an elevation of 200 feet along the coast and in the Santa Ana Canyon area. There is a classic forebay and pressure configuration of sediments. Recharge of groundwater is accomplished through percolation in the forebay, and in recent times from injection wells along the coast.

Figure 3 is a cross section of the coastal geology where seawater intrusion has occurred.

Early settlers of the Orange County area had found an ideal area for agriculture due to the moderate climate and availability of artesian wells. Agricultural pumping exceeded the safe yield of the system; consequently in the early 1920's artesian pressure levels were lowered below sea level and by 1931 the Talbert aquifer was intruded by seawater as far inland as 1.4 miles. Seawater intrusion continued, moving steadily inland and forcing the City of Laguna Beach to abandon their wells in 1947. Newport Beach lost their wells in 1953 and by 1963 seawater had moved as far as 3-1/2 miles inland from the ocean. Although OCWD managed to prevent further and more widespread damage through massive percolation of imported water into the forebay, the need for a coastal barrier system was obvious. Preliminary studies indicated that to develop an efficient hydraulic barrier to maintain intrusion control would require 30,000 acre-feet of water per year. In water-scarce Southern California this is a substantial quantity; and after weighing all the factors, including consideration of availability of supply, reliability, environmental problems, quality, and program costs, it was determined the best source for barrier injection would be reclaimed water. Since 1962 OCWD has been in the process of developing its coastal barrier project to utilize salvaged wastewater.

FACILITIES DESCRIPTION

The Coastal Barrier Project currently consists of Water Factory 21, an advanced waste treatment facility; a series of 23 injection wells; 31 monitoring wells; 5 supplementary deep wells and a battery of 7 extraction wells.

The water factory is designed to treat 15 million gallons per day of activated sludge secondary effluent provided through the facilities of the Orange County Sanitation

District. The advanced waste treatment process includes lime clarification, ammonia stripping, recarbonation, mixed media filtration, activated carbon adsorption, demineralization and chlorination.

The 23 injection wells are multiple casing units that inject into the four aquifers subject to the effects of seawater intrusion. The wells are located at 600-foot intervals in precast 6' x 10' concrete vaults located in a city street 3-1/2 miles inland from the coast. The wells vary in depth from 90 to 430 feet. Each well has the capacity to inject 450 gallons per minute. Figure 4 is a typical injection well.

The 31 monitoring wells are distributed landward and seaward of the injection line. The majority of the monitoring wells are multiple casing facilities mirroring the injection well installations.

To provide necessary supplementary waters to assure barrier supply, 5 conventional wells have been drilled to produce from a deeper aquifer not subject to seawater contamination. These wells, ranging from 850 to 1150 feet deep and capable of furnishing 3500 gpm each, are located adjacent to WF 21.

To assure a seaward gradient from the injection mound, and to regulate the amount of water that will move towards the ocean, 7 extraction wells have been constructed about 2 miles inland. These wells, optimized, produce 300 gpm each.

Figure 5 shows the relative location of the barrier facilities.

WATER FACTORY 21 PERFORMANCE

Because the reclaimed water produced by the plant will ultimately commingle with native groundwater and eventually be used for domestic, agricultural and industrial purposes, very stringent quality standards have been imposed by the California Regional Water Quality Control Board and the State Department of Health. The requirements are tabulated in Table 1.

Figure 6 is a flow diagram showing liquid processing of the salvaged wastewater. Because the average wastewater in Orange County typically contains approximately 1,000 milligrams per liter total dissolved solids, it is necessary to provide demineralization for a part of the reclaimed effluent in order to satisfy injection quality standards for TDS. Since July 1977 the District has been operating a 5 mgd reverse osmosis demineralization plant designed to provide 90 percent rejection of all salts while achieving an overall product water recovery of 85 percent. The schematic flow of the RO system is shown on Figure 7. The system is composed of pretreatment of the activated carbon effluent by adding chlorination and filtration, followed by RO membrane processing and posttreatment. Table 2 is a summary of the average RO unit performance.

By regulation the wastewater must be blended at least 50 percent with demineralized or deep well water prior to injection into the subsurface. Table 3 is a compilation of the quality of blended injection water compared to regulatory requirements for all quality parameters.

In addition to these quality considerations as indicated in Table 1, the District conducts a virus monitoring program to ascertain the efficiency of virus removal through the AWT process. To date, no viruses have been determined to have survived the treatment procedure.

The District maintains its own State approved laboratory to monitor the chemical and biological performance of the plant. Virus work is performed by contract with a local consulting firm.

BARRIER PERFORMANCE

Quality Procedures

The product water from the treatment process is pumped to the 23 injection wells for placement in the subsurface. The maximum injection pressure is 20 psi, to prevent damage to gravel pack and well seals of the injection units. The injected water and receiving groundwater is measured quantitatively and qualitatively on a daily basis, following a fixed schedule that provides for daily, weekly and monthly measurements. Figures 8 and 9 indicate the injection rate for calendar year 1978 showing the amount and the composition of the injected water. The injection water quality is continuously monitored and analyzed. Twice daily, grab samples are measured for chlorine residual, and every two hours the pH, conductivity and turbidity are analyzed. Each 24 hours a composite sample is tested for ammonia nitrogen, organic nitrogen, total kjeldahl nitrogen, calcium, alkalinity, fecal coliform, and total coliform. Once a week composite samples are tested for TDS, hardness, magnesium, sodium, chloride, fluoride, boron, sulfates, foaming agents, color, cyanide, and phenol.

The groundwater quality monitoring program is conducted on samples collected from the four aquifers exposed to seawater intrusion. At weekly intervals four preselected wells are tested for COD, conductivity, ammonia nitrogen, and chloride, color and odor. Monthly and semiannually all the observation wells are checked for conductivity and the presence of chloride.

Due to the special nature of the injection water, particular interest centers on the measured conductivity of the water, the determination of the presence of coliforms, and the potential presence of virus. Table 4 indicates the conductivity of the water that comprises the injection flow.

The conductivity of the receiving waters varies from 1,175 μmhos/cm to as low as 375 μmhos/cm, with an average of near 600 μmhos/cm which is somewhat similar to the injection source, resulting in the potential of obscuring the determination of displacement of native water by injection supply. Figure 10 is a summary of the electrical conductivity of the injection water for calendar year 1978.

Tests for total coliform bacteria and fecal coliform are conducted at least each 48 hours on the final blended supply. No fecal coliform has ever been detected in the injection water. During calendar year 1978 tests for total coliform indicated positive results on 16 occasions. Table 5 is a summary of the results of total coliform testing.

An analysis of coliform occurrence indicates that bacteria were present only when the plant was operating at low flows or coming back on line following a shutdown, which implies some limited bacteria growth during shutdown periods.

Water Levels

Since the inception of the hydraulic barrier program in October 1976, OCWD has injected 33,338 acre-feet of water into the subsurface. The principal objective of the program is to maintain sufficient water levels to prevent seawater from further penetration into the groundwater reserves of the County. It is essential that adequate pressures be established to protect the fresh water, particularly during times when the basin, for any circumstance, might be drawn down substantially below sea level.

As might be expected in a pressure zone, the injection mound created by placement of water in the relatively coarse materials of the exposed aquifers is quite sensitive to injection flow rate. Figures 11 through 16 are water levels measured in the Talbert aquifer from July through December 1978. The July contours show water levels on the fourth day of injection following an extended plant shutdown. As indicated, a mound was taking shape, although water levels in the area had not yet achieved sea level. August contours show water levels above sea level after 34 days of injection. The average levels had risen 2 feet and the barrier mound approximately 4 feet. At the barrier midpoint the internodal level was 5 feet (or more) above sea level. By September, the entire barrier mound was above sea level, with internodal levels of over 8 feet above sea level. The October contours represent barrier conditions after 7 days of reduced flow. An injection mound still exists, but there is a general loss of elevation, and the internodal average is depressed to about 2 feet above sea level. Contours representing November water levels following 26 days of 20 mgd injection flows show a strong resumption of the hydraulic mound with internodal elevations at the barrier midpoint of 12 feet above sea level. The December contours represent barrier conditions one day after a very low plant flow. The injection ridge has broadened and dropped several feet.

Not surprisingly it has been concluded that steady flow averaging between 12 mgd and 20 mgd, depending upon inland water elevation, is the optimum operational level. Studies are continuing in order to optimize injection rate for any given overdraft condition or limitation on the barrier supply.

The sedimentary section in the intruded area when analyzed as a unit is rather consistent; however the transmissivity characteristics vary within each zone rather widely. Table 6 is a summary of computed transmissivity and storage coefficient of each aquifer. Transmissivity is the theoretical quantity of water that will flow in gallons per day per foot of aquifer width. Storage coefficient is the theoretical volume of water an aquifer releases or stores per unit surface area of aquifer per unit change of head.

Because of the excellent permeability of the receiving sediments and the high quality of the injection water, the injection wells, after initial development, have been in continuous operation. It is anticipated that redevelopment will be required as injection rates diminish through clogging or other phenomena. This work is scheduled to occur when the line pressure on the distribution system equals the aquifer system pressure, and the District is not able to sustain an adequate hydraulic mound.

Table 7 is a two-year record of a typical well performance comparing injection rate, pressure, and gpm per unit of pressure.

OPERATIONAL COSTS

A summary of the AWT, RO and barrier costs is shown in Tables 8 and 9. Table 8 is a compilation of the annual operations and maintenance costs of the entire system, and Table 9 is a summation of total costs including capital and annual expenses. The costs are a tabulation of actual expenditures during one-year operation of the District's Water Factory. Detailed cost records are maintained to account for treatment processes including personnel expenses, utility costs, chemicals, and all maintenance expenses. All capital costs are amortized over service life of 20 years at 7 percent interest rate with a plant factor of 90 percent.

TABLE 1

REGULATORY AGENCY REQUIREMENTS FOR INJECTION WATER

OCWD WASTEWATER RECLAMATION AND INJECTION PROJECT

CONSTITUENT	MAXIMUM CONCENTRATION (mg/1)
Ammonium	1.0
Sodium	110.0
Total Hardness ($CaCO_3$)	220.0
Sulfate	125.0
Chloride	120.0
Total Nitrogen	10.0
Fluoride	0.8
Boron	0.5
MBAS	0.5
Hexavalent Chromium	0.05
Cadmium	0.01
Selenium	0.01
Phenol	0.001
Copper	1.0
Lead	0.05
Mercury	0.005
Arsenic	0.05
Iron	0.3
Manganese	0.05
Barium	1.0
Silver	0.05
Cyanide	0.02
Electrical Conductivity	900 μmhos/cm
pH	6.5 to 8.0
Taste	None
Odor	None
Foam	None
Color	None
Filter Effluent Turbidity	1.0 JTU
Carbon Adsorption Effluent COD	30 mg/1
Chlorine Contact Basin Effluent	Free Chlorine Residual

Reclaimed wastewater must be blended at least 50% with demineralized (RO effluent) or deep well water. Reclaimed wastewater must be tested for virus.

TABLE 2

RO PLANT PERFORMANCE
(Typical)

Constituent	Inflow quality (Activated carbon effluent)	Product Quality
Sodium	210 mg/l	11.0 mg/l
Total hardness	300 mg/l	Trace mg/l
Sulfate	280 mg/l	0.8 mg/l
Chloride	240 mg/l	16.0 mg/l
Ammonium	45 mg/l	Trace
COD	15 mg/l	1.5 mg/l
EC	1460 μmhos/cm	70 μmhos/cm

TABLE 3

BLENDED WATER QUALITY
(Typical)

Constituent	Unit	Regulatory Limit	Quality Achieved
EC	μmhos/cm	900	784
Turbidity	JTU	1.0	0.42
Na	mg/l	110	108
Ca	mg/l	--	37
Mg	mg/l	--	0.5
Cl	mg/l	120	103
SO_4	mg/l	125	83
Alk ($CaCO_3$)	mg/l	--	121
NH_3-N	mg/l	1.0	.86
Org-N	mg/l	--	.70
PO_4-P	mg/l	--	--
B	mg/l	1.0	.86
F	mg/l	0.8	.50
COD	mg/l	30	10
TOC	mg/l	--	--
MBAS	mg/l	0.5	0.08
Phenol	μg/l	1.0	1.0
$CHCl_3$	μg/l	--	--
PCB's	μg/l	--	--
Pesticides	μg/l	0.01*	--
As	μg/l	50	2.6
Ba	μg/l	1,000	14.0
Cd	μg/l	10	0.6
Cr	μg/l	50	8.8
Cu	μg/l	1,000	12.3
Fe	μg/l	300	71.0
Pb	μg/l	50	2.8
Mn	μg/l	50	4.6
Hg	μg/l	5	2.4
Se	μg/l	10	1.8
Ag	μg/l	50	0.8
Zn	μg/l	--	156
Cn	μg/l	200	<10.0

*Concentration above which pesticides not found in any sample.

TABLE 4

INJECTION WATER ELECTRICAL CONDUCTIVITY

Component	EC in µmhos/cm
Advanced waste treatment	1,460
RO plant	70
Deep wells	350
Average injected water	690

TABLE 5

TOTAL COLIFORM

Month	No. of Samples	No. of Times Positive	Ave. Colonies /100 ml	Max. Colonies /100 ml
Jan	16	0	0	
Feb	15	2	.26	3
Mar	18	0	.166	
Apr	15	6	1.86	8
May	13	1	2.0	33
June	13	2	2.0	28
July	9	0	0	
Aug	18	0	0	
Sept	15	0	0	
Oct	17	4	.47	5
Nov	15	1	.06	1
Dec	14	0	0	

TABLE 6

BARRIER AQUIFER TRANSMISSIVITY

Aquifer	Transmissivity gpd/ft.	Storage Coefficient
Talbert	53,000 - 660,000	2.16×10^{-4}
Alpha	26,000 - 200,000	1.90×10^{-5}
Beta	36,000 - 616,000	2.32×10^{-4}
Lambda	35,000 - 132,000	2.30×10^{-5}

TABLE 7

INJECTION PERFORMANCE
WELL I-13 (TALBERT)

Date	gpm	psi	Efficiency*
Mar. 1977	244	+ 4	61
Nov. 1977	211	+ 6	35
Mar. 1978	319	+10	32
Nov. 1978	348	+13	27
Mar. 1979	348	+15	23

*gpm/psi

TABLE 9

OPERATING AND CAPITAL COST SUMMARY
$/MG

	Capital	O & M	Total
AWT Plant	209	285	494
RO Plant	171	449	620
Injection System	17	35	52
Blended Water Cost (Plant Product Only)	340	496	836
Injected Water Cost (Includes Deep Well Water)			700

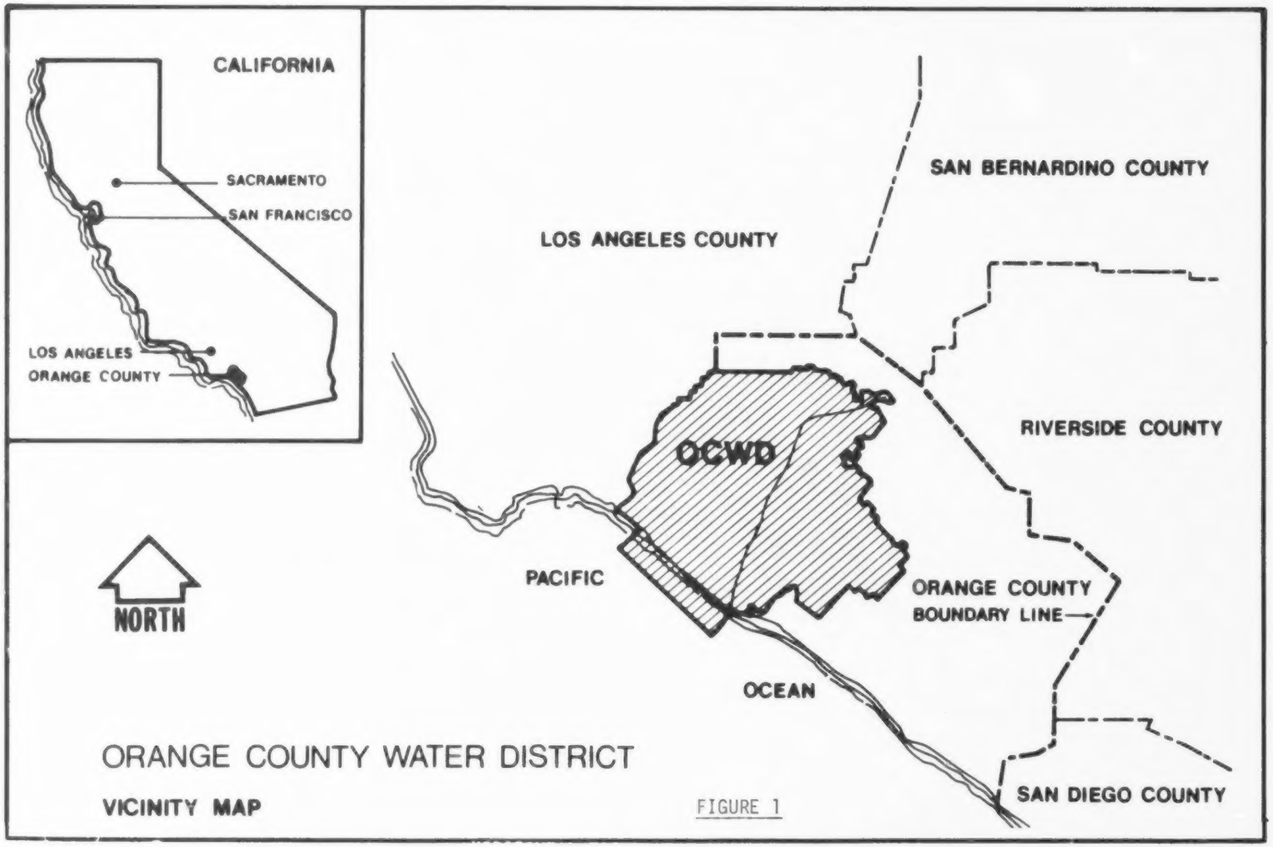
TABLE 8

WATER FACTORY 21 AND BARRIER FACILITIES
ANNUAL COST OF OPERATIONS AND MAINTENANCE

15 mgd AWT plant - 5 mgd RO plant		
Salaries		$ 613,000
Operations	$315,000	
Maintenance	238,000[1]	
Admin/Eng.	60,000	
Utilities		1,000,000
Electricity	828,000	
Gas	166,000	
Water	6,000	
Chemicals		222,800
Lime	61,000	
Alum	2,400	
Polymer	15,000	
Sulfuric Acid	24,000	
Chlorine	112,000	
SHMP	8,400	
Maintenance		513,600
Parts and Materials	260,000	
Equipment Rentals	18,000	
Uniforms	10,000	
Special Dept. Expense	12,000	
RO Maintenance Contract	213,600[2]	
TOTAL ANNUAL O & M COST		$2,349,400
Injection system		
Personnel		$ 69,000
Utilities (gas)		43,000
Maintenance		64,000
TOTAL INJECTION SYSTEM COST		$ 176,000
TOTAL ANNUAL COSTS		$2,525,400

1. Maintenance labor costs include some plant modifications completed during the year which were not capitalized, e.g. modification of upflow carbon columns to downflow.

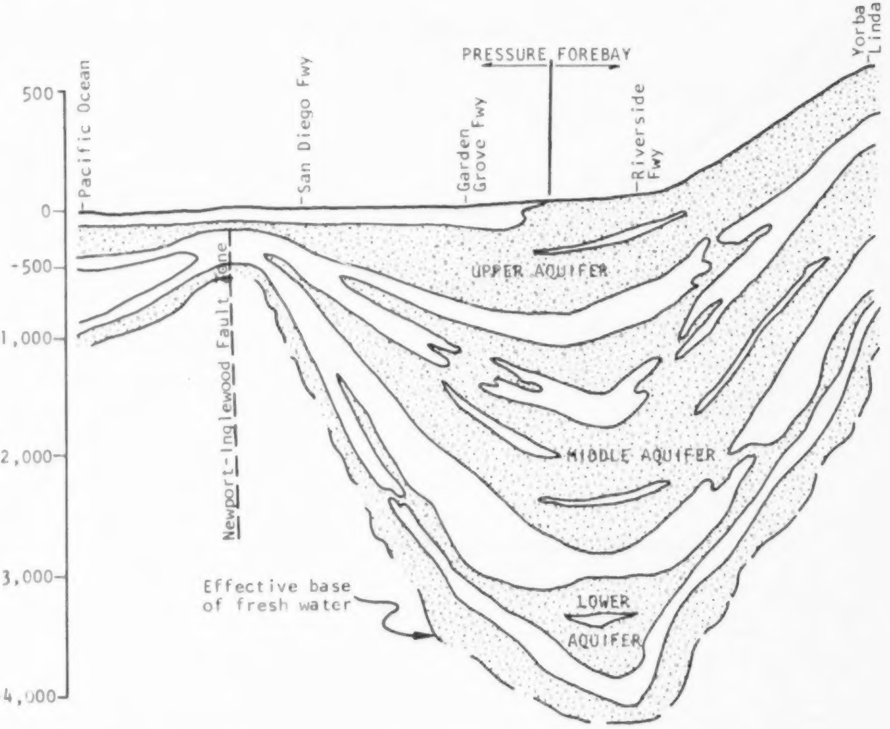
2. RO maintenance contract includes all membrane replacement costs, cartridge filter replacement, membrane cleaning, routine preventative and emergency maintenance.



ORANGE COUNTY WATER DISTRICT

VICINITY MAP

FIGURE 1



Cross-section of Orange County Groundwater Basin

FIGURE 2

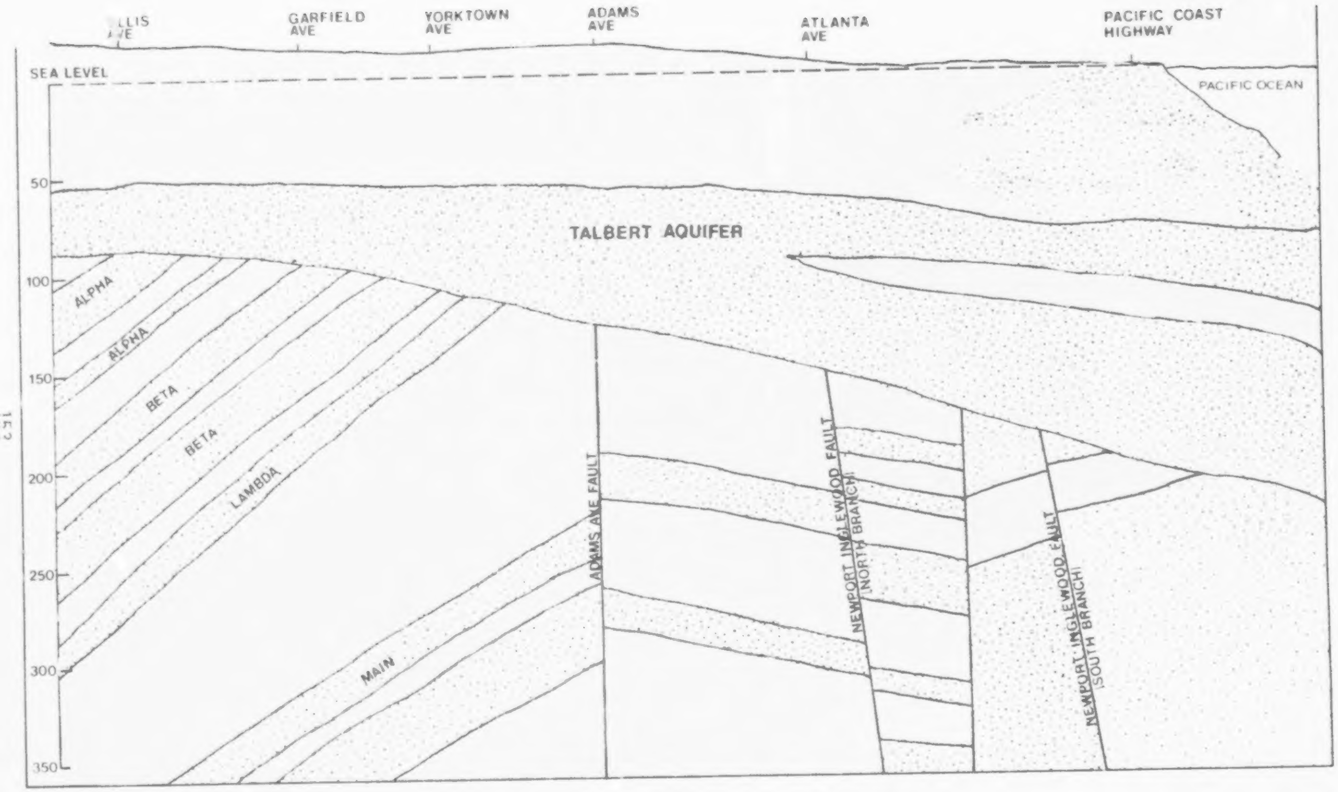
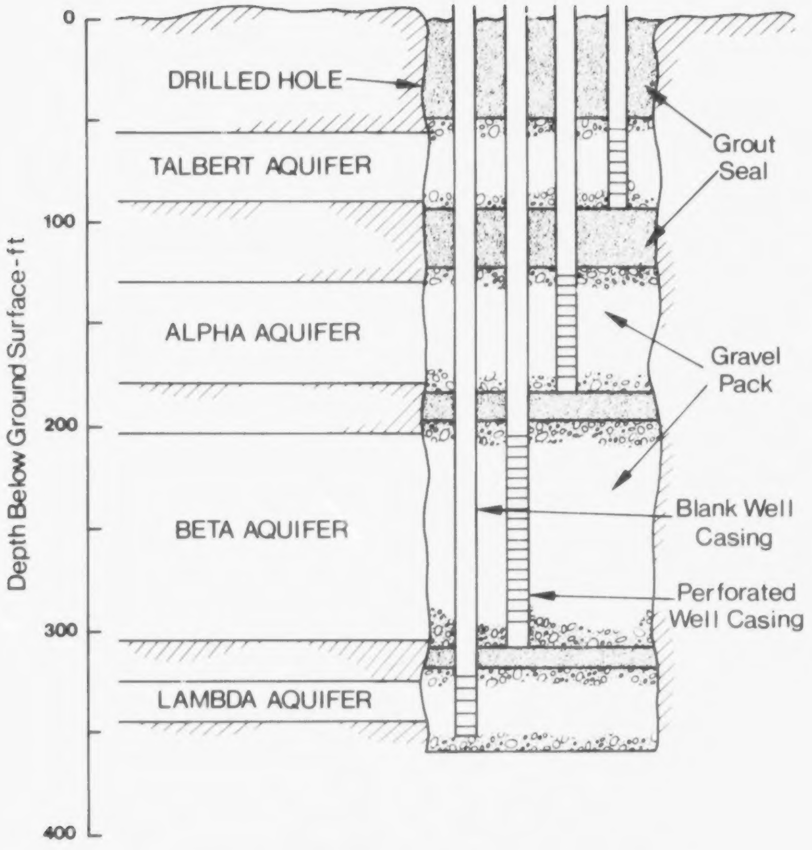


FIGURE 3 GENERALIZED CROSS SECTION



Typical Injection Or Observation Well

FIGURE [illegible]

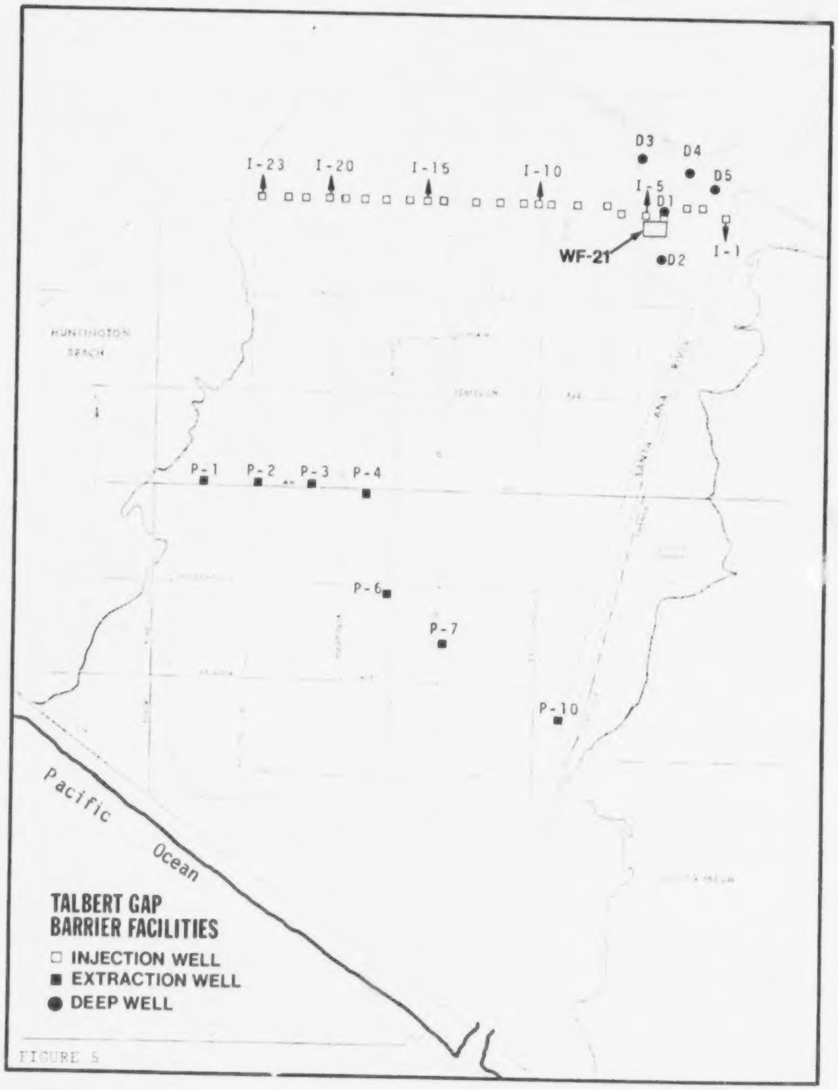
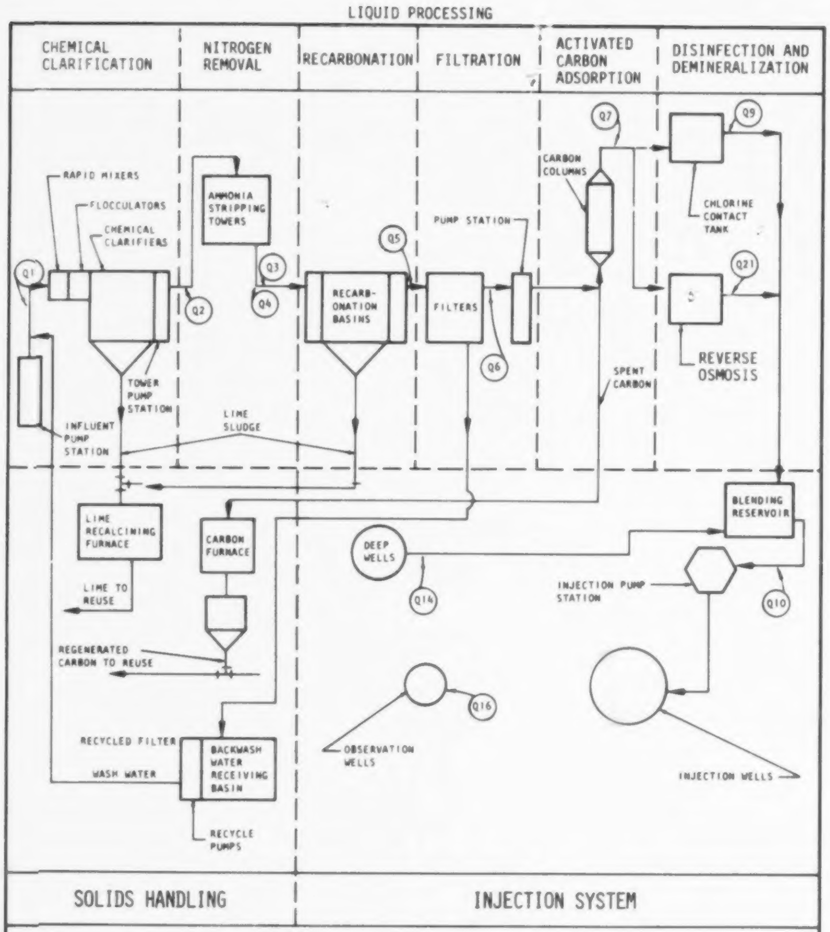
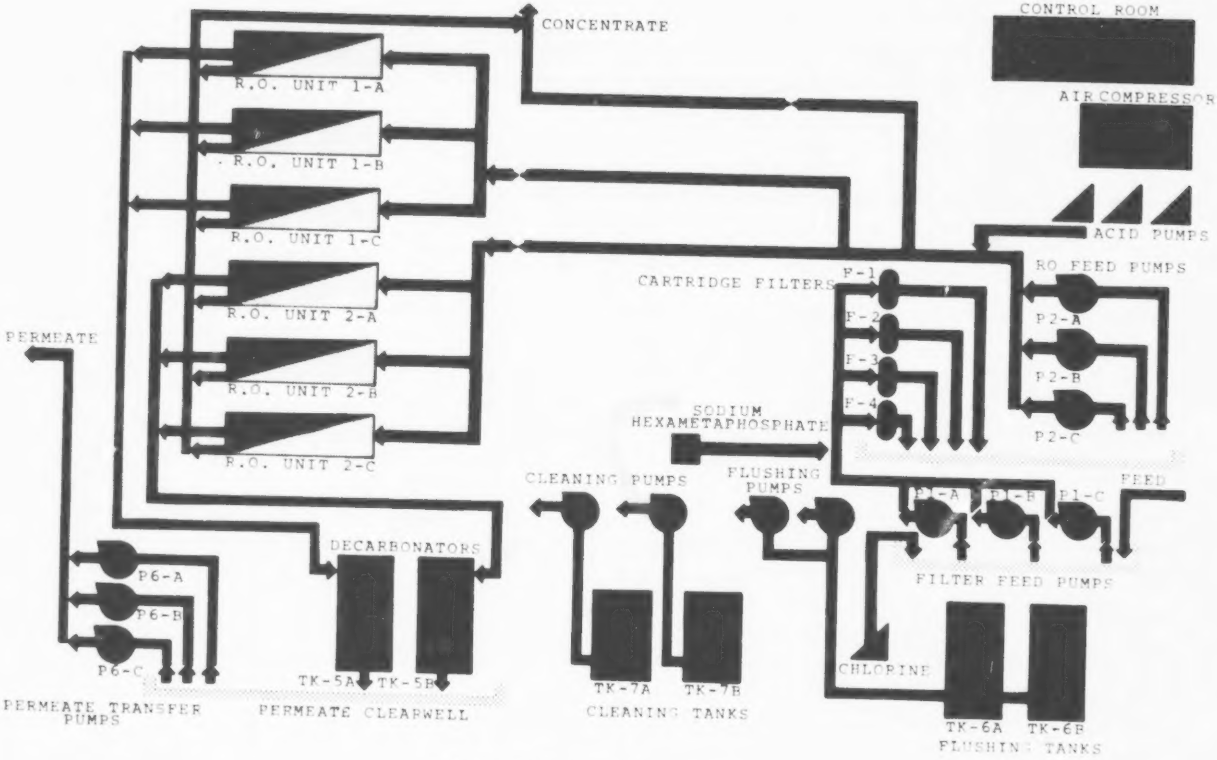

I-23
I-20
I-15
I-10
I-5
I-1
D3
D4
D5
D1
D2
WF-21
HUNTINGTON BEACH
SANTA ANA RIVER
P-1
P-2
P-3
P-4
P-6
P-7
P-10
Pacific Ocean
TALBERT GAP
BARRIER FACILITIES
□ INJECTION WELL
■ EXTRACTION WELL
● DEEP WELL

FIGURE 5

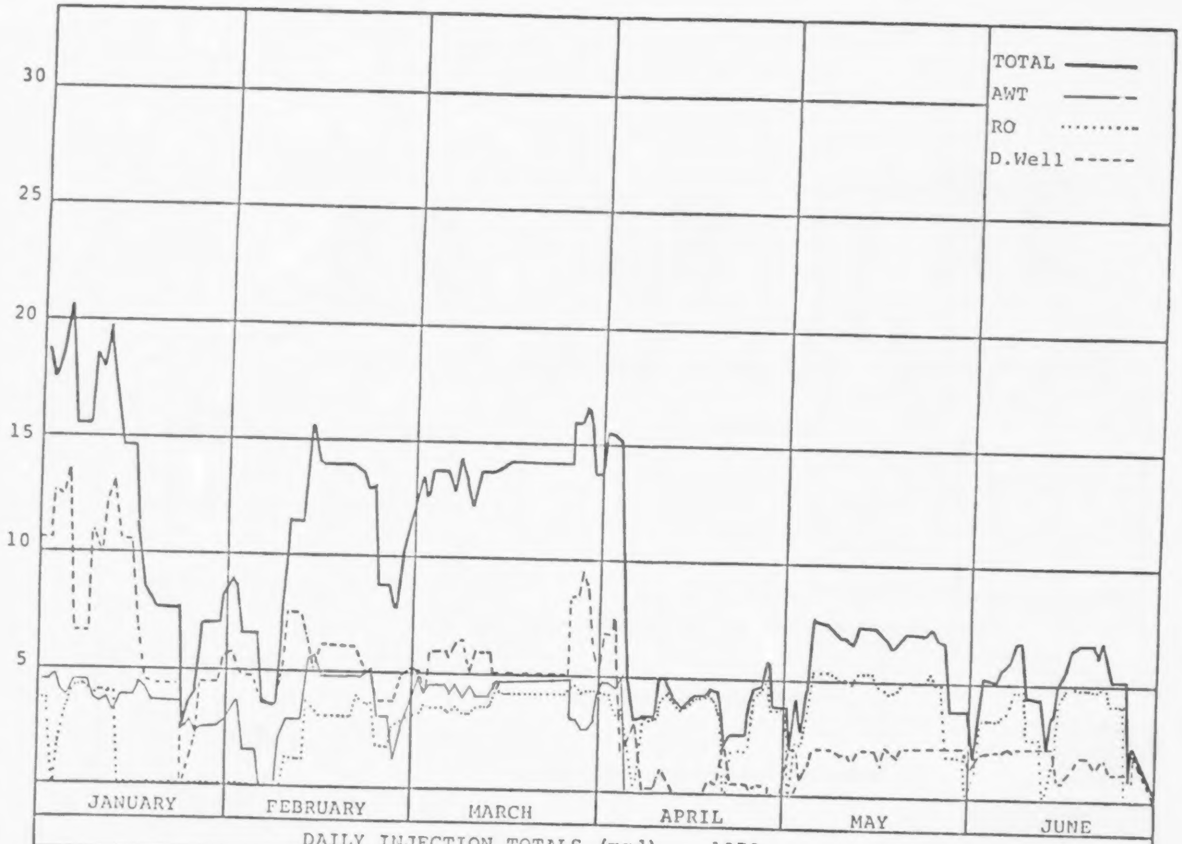


FLOW SCHEMATIC & SAMPLING LOCATIONS

15 MGD WASTEWATER
RECLAMATION PLANT



5 MILLION GALLONS PER DAY
REVERSE OSMOSIS FLOW SCHEMATIC



DAILY INJECTION TOTALS (mgd) 1978

FIGURE 8

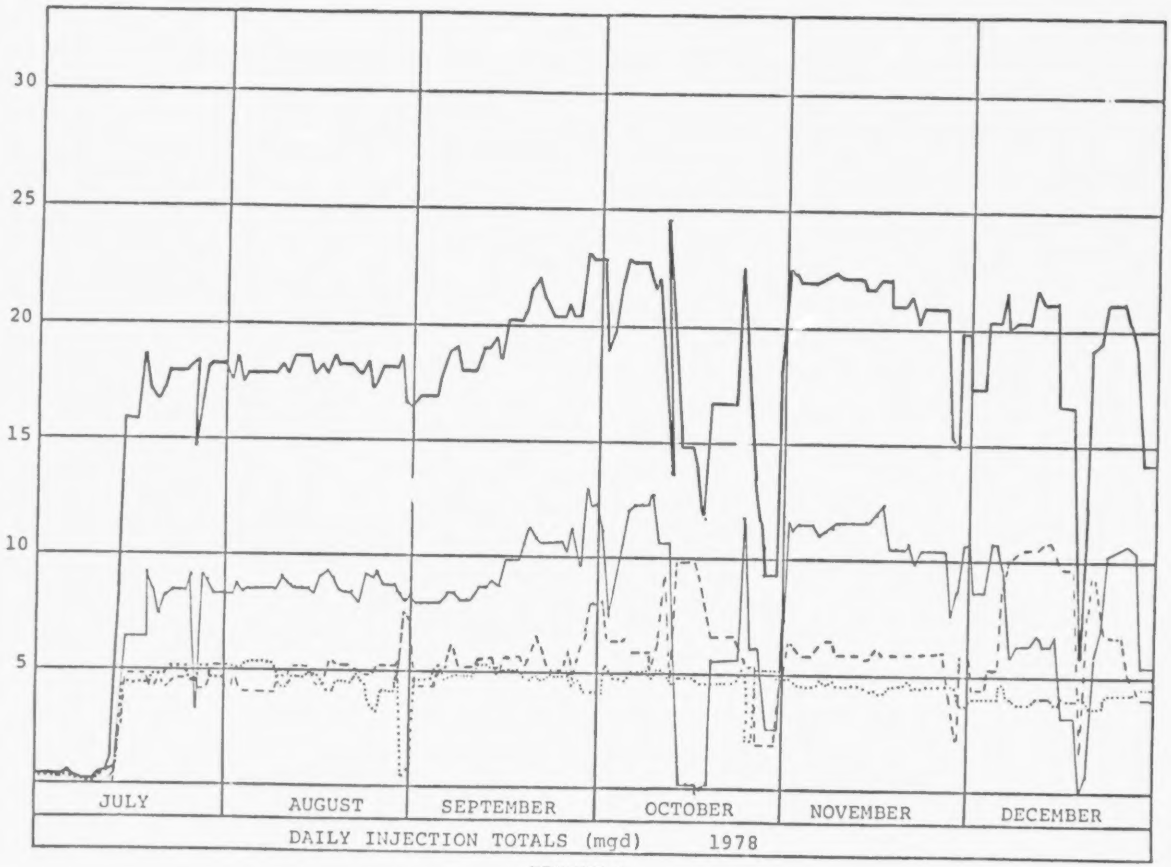
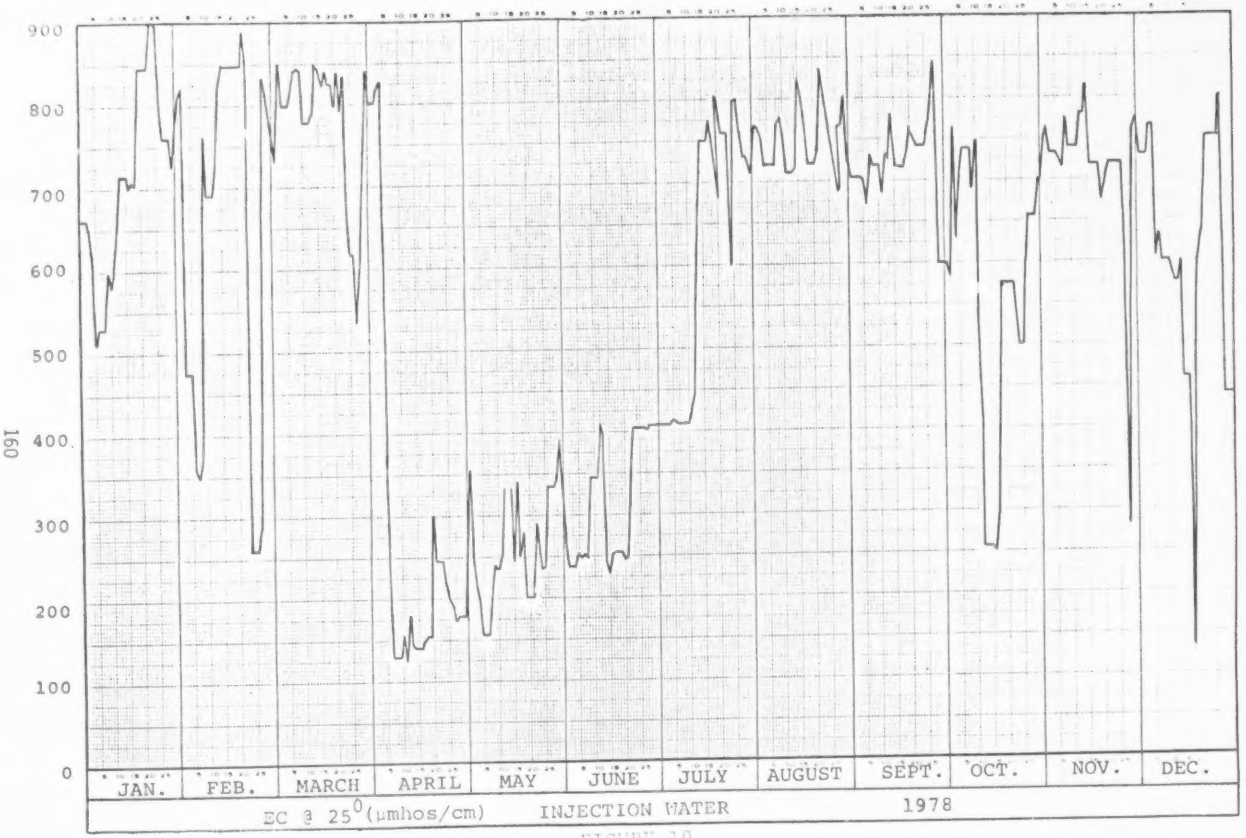
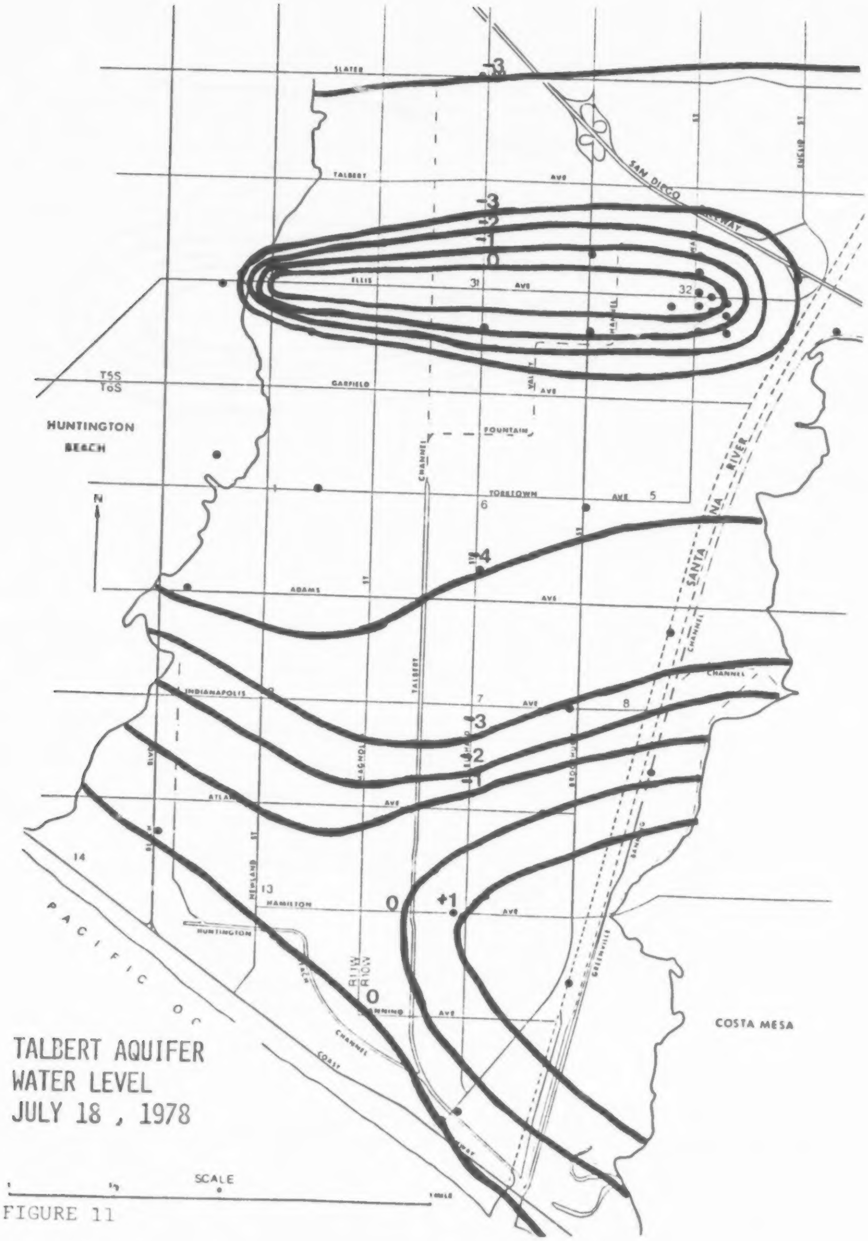

30
25
20
15
10
5
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
DAILY INJECTION TOTALS (mgd) 1978

FIGURE 9



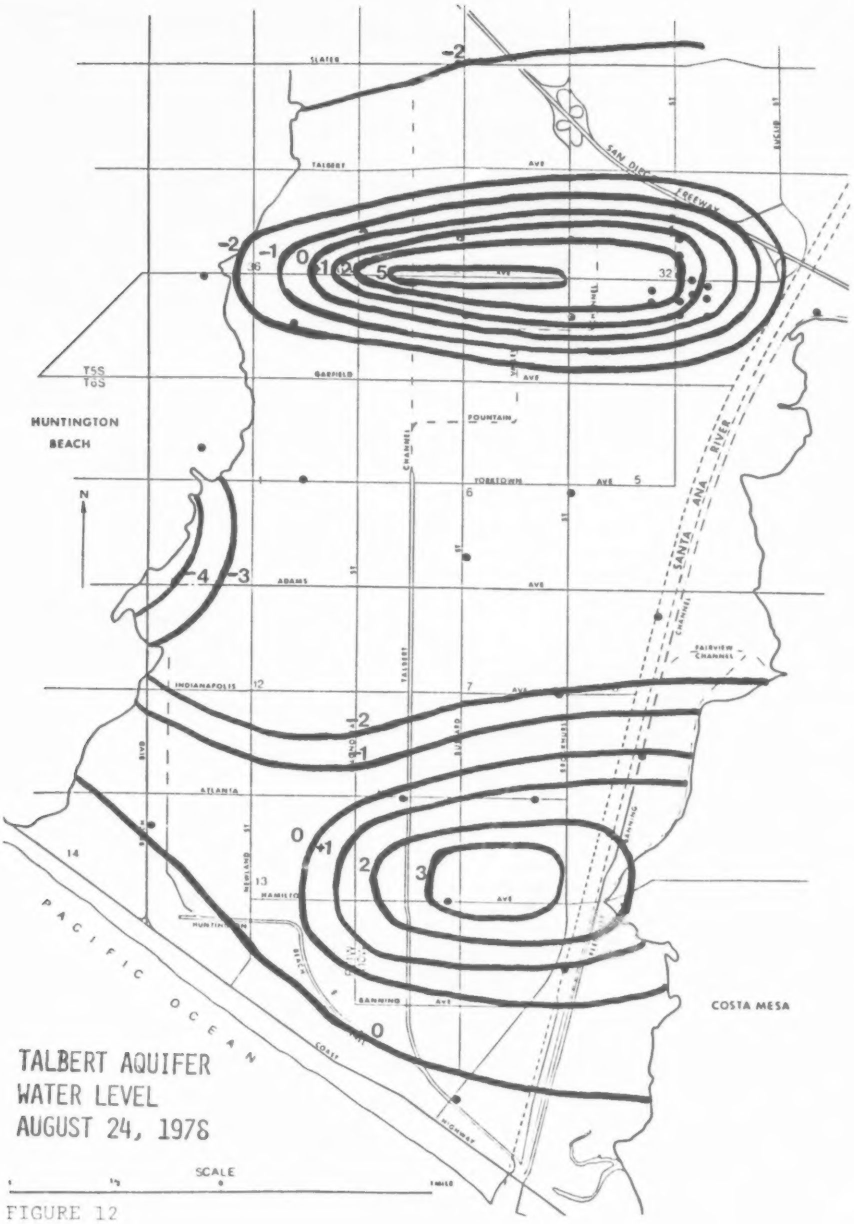
EC @ 25^0(μmhos/cm) INJECTION WATER 1978

FIGURE 10



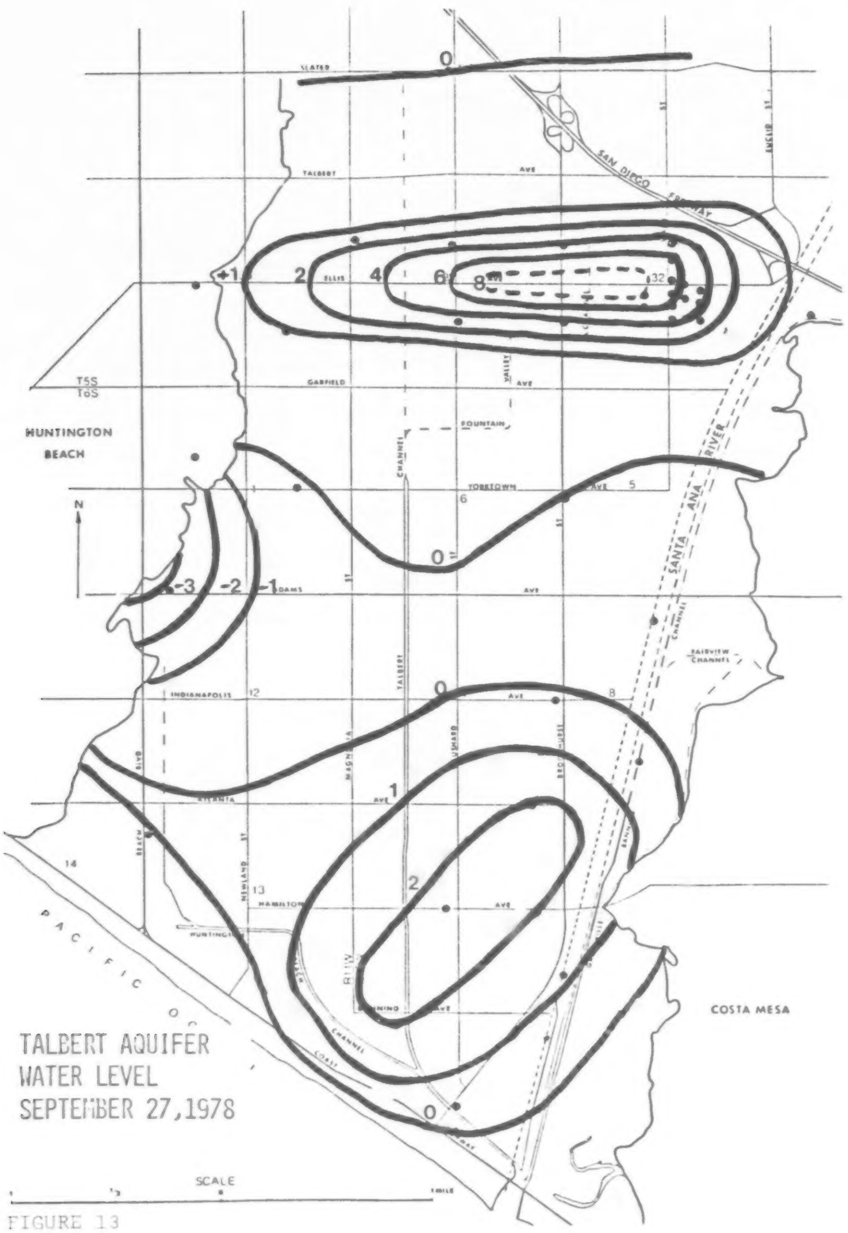
TALBERT AQUIFER
WATER LEVEL
JULY 18 , 1978

FIGURE 11



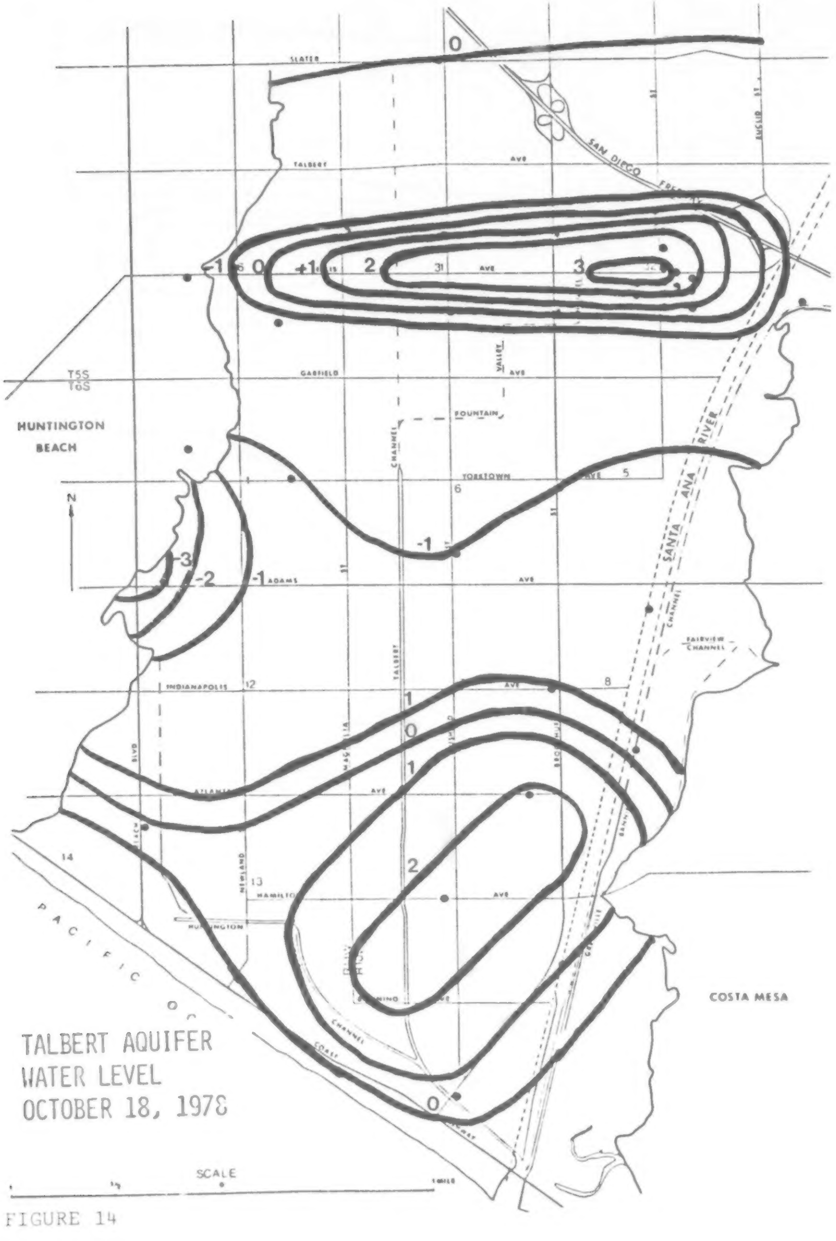
TALBERT AQUIFER
WATER LEVEL
AUGUST 24, 1978

FIGURE 12



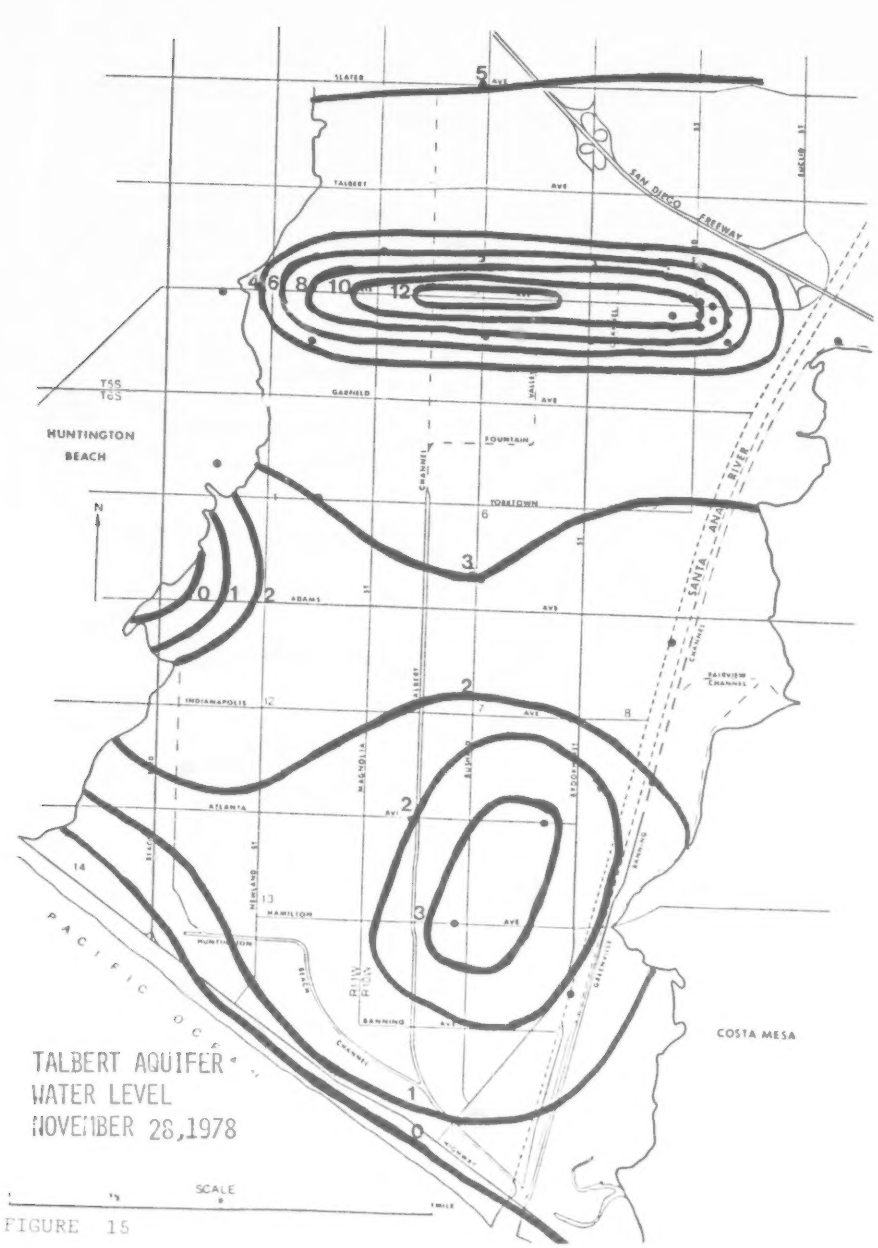
TALBERT AQUIFER
WATER LEVEL
SEPTEMBER 27,1978

FIGURE 13



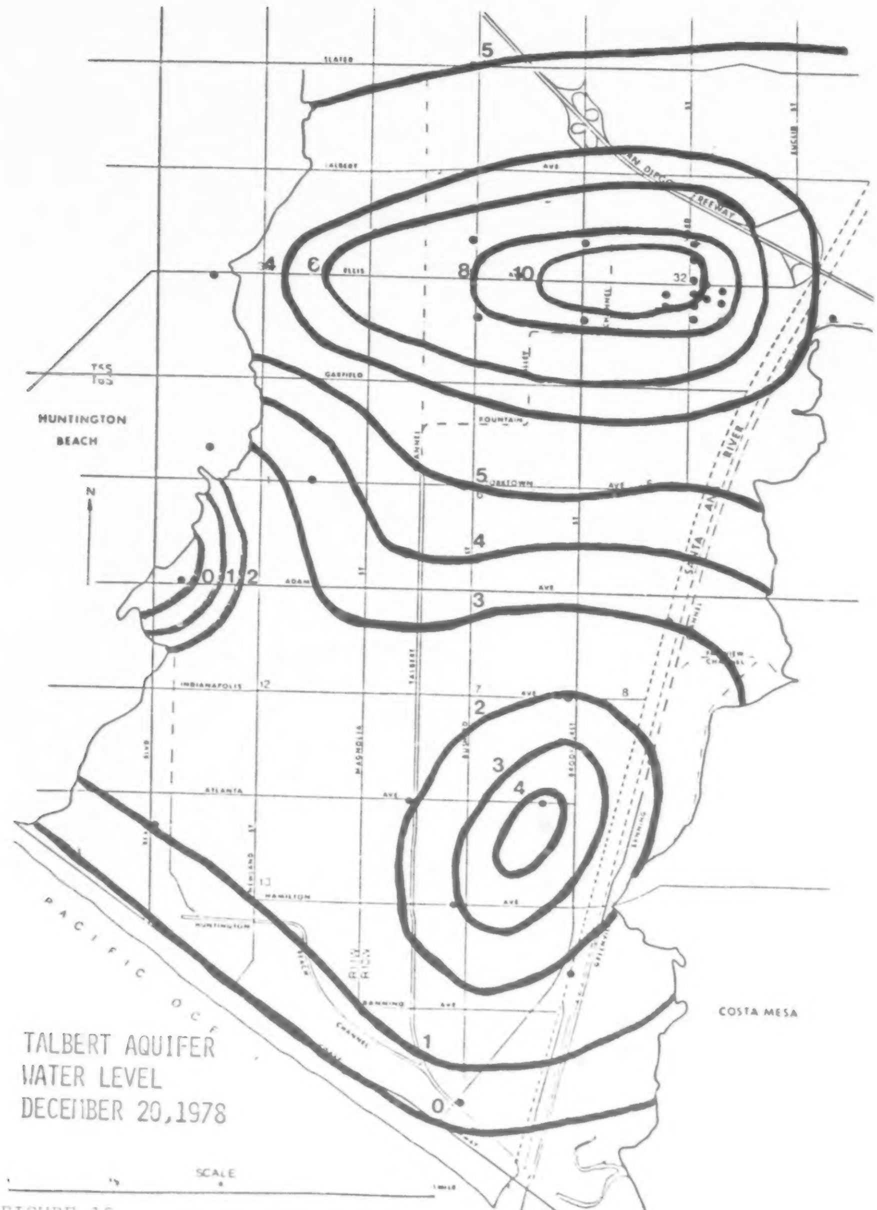
TALBERT AQUIFER
WATER LEVEL
OCTOBER 18, 1978

FIGURE 14



TALBERT AQUIFER
WATER LEVEL
NOVEMBER 28,1978

FIGURE 15



TALBERT AQUIFER
WATER LEVEL
DECEMBER 20,1978

FIGURE 16

WASTEWATER IN DRINKING WATER SUPPLIES

Michael D. Swayne, PhD
Vice President, SCS Engineers

Gregory H. Boone
Systems Engineer, Jones & Associates

David H. Bauer, John S. Lee, James T. Morgan
SCS Engineers

John English
Project Officer, EPA-MERL, Cincinnati

Water reuse is a term generally used in relation to the treatment of wastewater generated by one activity to be used as the water supply for another activity. In these cases, the reuse application is designed as an integrated system, ensuring that the treated wastewater meets supply specifications in terms of both design and operation. Use of municipal and industrial wastewater after discharge and dilution by receiving waters is another form of water reuse that is widely practiced. However, this form of water reuse poses a number of technical, political and social problems. It is often difficult or impossible to do an adequate system design because the wastewater sources (dischargers) are numerous and outside the control of the water supply agency. Since the wastewater is conveyed to streams and rivers with uncontrolled characteristics, the wastewater will be modified in a manner which is difficult to estimate from the existing state of knowledge. This is particularly true for many substances now suspected of being a health risk. These include certain heavy metals, pesticide/insecticides, aromatics, aliphatic solvents, phenols and several others, where data on their fate in the environment is limited. Even more basic is the fact that it has been difficult to simply determine the identities and characteristics of wastewater dischargers upstream from water supply points.

The purpose of this paper is: (1) to present the development of a computerized data base system designed to facilitate the identification and the extent to which wastewater dischargers impact surface water supply systems, (2) to show estimated impacts based on presently available information, (3) and to discuss current developments which will improve these estimates in the near future.

The Wastewater in Receiving Water (WIRW) data base system was developed by SCS Engineers under contract to the Municipal Environmental Research Laboratory, Cincinnati, Ohio[1]. The data base was loaded with presently available data from national level files. This included 1246 water supply sources from 194 basins serving 525 cities with populations greater than 25,000.

---

[1] Wastewater in Receiving Waters at Water Supply Abstraction Points, SCS Engineers, EPA Contract No. 68-03-2592, Project Officer John English.

Data in the system was used to develop information on: the number of upstream wastewater dischargers by type, estimation of cumulated wastewater discharge flow and the ratio of wastewater flow to stream or river flow. The results ranged from 142 utilities with no dischargers identified to many utilities where the wastewater constitutes a major portion of the water supply. Several utilities were determined to be using water from a source whose low flow was less than the combined upstream discharge flows. Water supplies serving cities near the bottom of large river basins were found to contain wastewater from several thousand dischargers. However, those water supplies with the highest percentage of wastewater relative to supply flow were generally small to medium sized creeks and rivers. Twenty-five cities with a total population of over seven million were determined to have surface water supplies containing from 2.3 to 16 percent municipal wastewater during average flow conditions.

GOAL AND OBJECTIVES

The goal of this study which led to the development of the data base system was to review presently available information and data contained in existing reports and other documentation to determine the impact of upstream wastewater dischargers at the point of the water intake for utilities utilizing surface water supplies.

The objectives of this study were to:

1. Identify all utilities supplying surface water to populations over 25,000.
2. Identify respective surface water names and locate intake points.
3. Identify and locate all municipal and industrial wastewater dischargers upstream from intake points.
4. Determine respective discharger category (type), flow and BOD loads.
5. Determine average and low flows at each intake point.
6. Determine ratio of the sum of discharger flows to water supply source flow (percent wastewater in drinking water).
7. For selected sites, estimate BOD load caused by upstream dischargers at supply intake point.
8. Project changes in load due to anticipated changes in wastewater treatment required by PL 92-500.
9. For the selected cities make a more detailed accounting of the quantities and types of municipal and industrial wastes.

APPROACH

The general approach to meeting these objectives and modifications required were as follows:

1. Utilities serving over 25,000 and the names of source waters were identified using the EPA Inventory of Water Supply (IPWS)[2] file. This file yielded 1246 source waters serving 540 utilities and was considered to be sufficiently complete and accurate to meet project objectives.

2. Locations of surface water intake points were also determined using the IPWS file. Unfortunately, the locations (latitude/longitude) of the intake points were not always available. For these cases an assumption of shortest distance between utility/city location and water supply was used.

3. Identities of upstream dischargers were determined using the Permit Compliance System (PCS).[3] While this file provides facility identities, it does not contain location data more precise than city or county name, nor does it contain discharge flow data or receiving water names. The procedure used was to sort the PCS file by county and city names and make discharge assignments to the nearest surface water.

4. Flow and BOD loadings for municipal dischargers were obtained from the Municipal Waste Facilities Inventory (MWFI)[4] file and the NEEDS[5] file. Unfortunately, the MWFI file is out of date for most regions and contains limited flow data. The NEEDS file contains good data on flow, but contains only about 50 percent of the universe of municipal dischargers. Locational data (lat/long or receiving water name) were also limited on these files.

5. Source water supply flow data were also often difficult to obtain. A search of USGS data files showed that out of 12,484 stations, less than 5,000 had sufficient data to compute a staisfactory mean annual flow statistic,

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[2] Inventory of Public Water Supplies File, Environmental Protection Agency, Office of Drinking Water, System Manager Patrick Tobin.

[3] Permit Compliance System, Environmental Protection Agency, Office of Enforcement, System Manager William Milligan.

[4] Municipal Waste Facilities Inventory File, Environmental Protection Agency, Office of Water Planning and Standards, System Manager Charles Conger.

[5] Survey of Needs for Municipal Water Treatment Facilities, Environmental Protection Agency, Office of Water Program Operations, System Manager James Chamblee.

and less than 3500 had sufficient data to compute a seven day ten year low flow statistic. Gauging stations with data were often not close to intake points; therefore, source water flows had to be approximated by extrapolation, or in some cases left blank.

6. A computerized data base was developed to store all the relevant data on cities, utilities, source waters and dischargers. The use of a hierarchical data base organization facilitates updating and retrieval of data for processing.

7. Discharger location or river mile distances were generally not readily available. Therefore, fate models assumed dischargers were concentrated at points midway between each utility. This assumption was estimated to cause an average error of about 10 percent in the value of pollutant load at the intake point. Other errors in flow and decay rate are considered more significant.

8. A detailed accounting of the types of industrial wastes was accomplished by examining the Standard Industrial Classification (SIC) code provided by the PCS file. Dischargers were divided into 28 types. Twenty-one types are essentially the same as those identified by the NRDC Consent Decree.[6]

The results of this study are considered to be significant and extremely useful and timely for the following reasons:

1. A Wastewater In Receiving Water (WIRW) data base system has been developed which can be updated relatively easily as more data become available, and which can efficiently handle data on large numbers of discharges and water supplies.

2. Identifiable links have been established between dischargers and utilities.

3. Water utilities which appear to be impacted by pollutants can be identified for further study.

4. The data can be used to help determine exposure and risks of human and wildlife populations to toxic pollutants.

RESULTS AND CONCLUSIONS

The completion and operation of the WIRW data base system using the existing data has provided a large amount of data in accessible form from which a number of interesting conclusions and insights can be drawn. The data can also be used as the basis for further analysis. It is important to understand the quality of original data sources, assumptions made, and limitations for further analysis. Present data accuracy and completeness will not support detailed or micro analysis at particular intakes. However, the data does provide an excellent national level reference useful for identifying those utilities which appear to be impacted and need to be investigated in greater detail.

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[6] Natural Resources Defense Council, Environmental Defense Fund and Citizens for a Better Environment (Plaintiffs) vs Russell E. Train (Defendant); U.S. District Court for the District of Columbia, 6/9/76.

The results presented in the following tables must be interpreted carefully. Obvious comparisons can be made between levels of wastewater impact for various cities within the WIRW data base. Interpretations of these comparisons may appear contradictory, depending on how the analyst views the data. For example, Philadelphia, Pennsylvania draws drinking water from Neshaminy Creek. About 3.8 percent of that water is estimated to be municipal wastewater during average flow conditions, and that utility serves a population of 759,000 people. On the other hand, Columbia, South Carolina serves 228,000 people from the Saluda River which is estimated to contain about 16 percent municipal wastewater during average flow conditions. It might be concluded that Columbia is more highly impacted because of the higher percentage of wastewater. Others might see Philadelphia as more highly impacted because a greater population is effected. Other criteria such as number of dischargers, river flow, or location may be used to analyze the data. The primary purpose of developing a data base was to facilitate the access and analysis of data by analysts with a variety of objectives.

A number of cities exhibit relatively high percent wastewater statistics. Columbia, South Carolina, for example, shows a degraded wastewater value of 10 percent during average flow conditions. This implies that the city's population is exposed to relatively high concentration of wastewater. However, this may be an invalid conclusion. Unfortunately, the data source (IPWS) file did not identify seasonal changes in the water supply, or the amount withdrawn from each source. For example, Columbia has another water supply, the Broad River, which has a lower concentration of wastewater. Therefore, the impact is less than indicated in the summary tables.

A percent wastewater figure greater than 100 percent may be interpreted several ways. The data presented is simply the total discharge flow estimate divided by the water supply source flow estimate. A value greater than 100 percent may indicate: inaccurate source data, water being used more than once, loss of water in the river due to evaporation, or loss to ground or consumptive withdrawals. It must also be understood that the percent wastewater data presented reflects that waste contributed only by municipal dischargers, since flow data for industrial dischargers was not available. Also, all percent wastewater values shown assume no in-stream degradation unless noted otherwise.

With these qualifications in mind, the following tables present statistical summaries of the data base. Table 1 presents the distribution of population versus percent wastewater in water supply. Table 2 presents a spatial distribution by federal regions of the number of water supplies containing various percentages of wastewater in water supplies. Tables 3 and 4 identify cities whose water supplies appear to be impacted the greatest.

Percent Municipal Wastewater by Population

Table 1 presents the population which utilizes surface water supplies containing various percentages of municipal wastewater. Table 1 shows that of the population utilizing surface water (almost 80 million) about half are exposed to zero or low concentrations of wastewater during both average and low flow conditions. About 20 million and 5 million persons are shown to be exposed to wastewater exceeding 10 percent and 100 percent respectively during low flow conditions. However, as noted previously, it is unknown to what extent alternative water supplies are used during low flow conditions or to what extent supplies are combined. Therefore, the data reflect maximum estimated impacts.

Percent Municipal Wastewater by Region

Table 2 presents the number of source waters in each federal region containing various percentages of municipal wastewater for average flow conditions. This table shows that for most regions a high percentage of source waters contain zero or a small percentage of wastewater. The numbers in parenthesis are the expected values if there were only random relations between percent wastewater in source waters and regions. These tables show that surface water supplies in Regions I, IX, and X are impacted less by wastewater than the national average and that surface water supplies in Regions III, IV, V, VI, and VII tend to be impacted more than the national average.

Cities Estimated to Have the Highest Percent of Municipal Wastewater

Table 3 presents 25 cities ranked according to percent municipal wastewater under average source water flow conditions. Included in Table 3 for reference are percent wastewater estimates based on a simple exponential decay fate model, and estimates of the number of municipal and industrial dischargers.

Certain utilities with higher estimates of percent wastewater were excluded from this summary because the resolution of the data sources were not considered sufficient.

The degraded pollutant estimates show some decrease from the conservative estimates. In one case, Alton, Illinois, it appears that most of the wastewater is discharged some distance upstream, since the nonconservative estimate (.22) is considerably less than the conservative estimate (3.2).

It is recommended that the utilities listed in Table 3 be considered as a "shopping list" of utilities to be investigated in more detail regarding the potential human exposure to wastewater pollutants, rather than as a list of the

Table 1

Distribution of Population by Percent Municipal Wastewater

PERCENT WASTEWATER	POPULATION DISTRIBUTION LOW FLOW PERCENT WASTEWATER x1000	POPULATION DISTRIBUTION AVERAGE FLOW PERCENT WASTEWATER x1000
0	32,174	32,174
0+-.05	9,144	8,833
.06-.2	34	6,646
.21-.5	1,184	2,542
.51-1.0	462	7,833
1.1-2.0	3,751	10,216
2.1-5.0	4,639	10,309
5.1-10	4,429	241
11-20	9,874	288
21-50	3,137	0
51-100	2,400	64
101-200	3,967	0
201-500	1,340	0
TOTAL	76,535	79,146

TABLE 2. DISTRIBUTION OF NUMBERS OF SOURCE WATERS IMPACTED BY REGION FOR AVERAGE FLOW CONDITIONS

% WASTE-WATER	REGION I	REGION II	REGION III	REGION IV	REGION V	REGION VI	REGION VII	REGION VIII	REGION IX	REGION X	TOTALS
0	119 (74)	35 (31)	87 (92)	53 (70)	23 (30)	16 (28)	4 (17)	19 (23)	37 (30)	16 (14)	409
0+-.05	1 (12)	4 (5)	20 (16)	9 (12)	6 (5)	9 (5)	3 (3)	8 (4)	3 (5)	6 (2)	69
.06-.2	1 (6)	2 (3)	10 (8)	9 (6)	1 (3)	5 (2)	3 (2)	0 (2)	4 (3)	1 (1)	36
.21-.5	1 (4)	3 (2)	4 (6)	8 (4)	2 (2)	3 (2)	1 (1)	3 (1)	1 (2)	0 (1)	25
.51-1.0	1 (9)	2 (4)	10 (11)	14 (8)	5 (4)	3 (3)	7 (2)	2 (3)	4 (4)	0 (2)	48
1.1-2.0	1 (10)	2 (4)	16 (12)	12 (9)	7 (4)	7 (4)	9 (2)	0 (3)	0 (4)	0 (2)	54
2.1-5.0	0 (6)	4 (3)	6 (8)	9 (6)	6 (3)	2 (2)	2 (1)	5 (2)	0 (3)	0 (1)	34
5.1-10	0 (1)	0 (0)	1 (1)	1 (1)	0 (0)	1 (0)	0 (0)	1 (0)	0 (0)	0 (0)	4
11-20	0 (1)	0 (0)	0 (1)	2 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3
21-50	0	0	0	0	0	0	0	0	0	0	0
51-100	0 (0)	0	0 (0)	0	0	0	0	0	2	0	2
101-200	0	0	0	0	0	0	0	0	0	0	0
201-500	0	0	0	0	0	0	0	0	0	0	0
TOTALS	123	52	154	117	51	46	29	38	51	23	684

Note: The numbers in parenthesis are the expected values if there were only random relations between percent wastewater in source waters and regions.

TABLE 3. SOURCE WATER IMPACT ACCORDING TO AVERAGE FLOW PERCENT WASTEWATER

State	City	Line	Source Water	Population X1000	Percent Wastewater		No. of Dischargers		
					Conservative(1)	Degraded(2)	Total	Municipal	Industrial
SC	Columbia	259	Saluda R	228	16	9.8	153	52	101
MI	Ypsilanti	323	Huron R	30	13	11	38	9	29
SC	Greenwood	258	Lk Greenwood/Saluda R	29	7.7	5.4	110	33	77
CO	Pueblo	495	Arkansas R	95	7.6	5.3	74	32	42
NJ	Little Falls	055	Passaic R	333	4.9	4.1	154	44	110
ND	Millburn	054	Passaic R	234	4.8	4.2	19	9	10
CO	Thornton	335	Clear Ck	60	4.5	4.2	63	12	51
IN	Indianapolis	464	White R	680	4.3	3.0	102	33	69
NJ	Elizabeth	166	Del-Raritan CA	500	4.3	3.9	17	5	12
NJ	Princeton	162	Del-Raritan CA	25	4.3	3.9	17	5	12
PA	Bryn Mawr/Philadelphia	149	Neshaminy Ck	820	3.8	3.5	30	9	21
PA	Middletown/Philadelphia	140	Neshaminy Ck	759	3.8	3.5	30	9	21
AL	Langdale	235	Chattahoochee R	25	3.8	2.3	39	21	18
AL	Birmingham	207	Cabaha R	650	3.6	3.4	19	5	14
GA	La Grange	234	Chattahoochee R	32	3.6	2.2	28	16	12
PA	Philadelphia	155	Schuylkill R	1950	3.5	2.5	240	65	175
TX	Ingleside	551	Nueces R	30	3.5	3.2	19	19	0
WI	Oshkosh/Appleton	273/274	Lk Winnebago	53	3.3	2.4	174	45	129
GA/AL	Columbus/Phenix City	237/236	Lk Oliver	134/28	3.2	1.5	42	0	42
CO	Westminster	334	Clear Ck	35	3.2	3.0	54	14	40
IL	Alton	380	Mississippi R	57	3.2	.22	4037	296	3741
TX	Dallas	539	Lk Ray Hubbard	878	2.8	2.7	12	4	8
OH	Bowling Green	327	Maumee R	26	2.8	1.6	380	139	241
CO	Englewood	339	S. Platte R	36	2.6	2.4	31	6	25
SC	Lancaster	267	Catawba R	25	2.3	1.5	169	17	152

(1) Cumulative percent wastewater estimates under average source water flow conditions.
(2) Cumulative percent wastewater estimates using exponential degradation model.

utilities with the greatest impacts. One reason is because of data resolution and lack of industrial flow data, and the other is that many of these cities use more than one water source. For example, Columbia, South Carolina uses three other sources in addition to the Saluda River, and Ypsilanti uses eight wells in addition to the Huron River.

Cities Estimated to Have the Highest Municipal Wastewater Loading

Another method of presenting impact is in terms of mass loading of pollutants on the population served. Assuming that the population for each city uses or is exposed to the same average flow of water per capita, then the mass loading of pollutants on the population is proportional to the population times the percent wastewater in the water supply.

Table 4 presents a list of twenty-five population centers which are estimated to have the greatest loading or exposure to municipal wastewater in drinking water supplies. The cities are ranked according to the product of population and the conservative estimate of percent wastewater. The degraded estimate averages 46 percent less than the conservative estimates.

SUMMARY

The Wastewater in Receiving Water (WIRW) data base is a tool which can support many types of analysis. Several of the uses have been indicated in this paper others are presented in the body of the report. However, it is important to stress here that this data base provides a significant framework never before assembled, for further data additions and practical use even in this embryonic stage. Never before has so much data on the relation between wastewater discharges and drinking water been assembled in such a comprehensive and useful form. Collecting data on 540 utilities across the nation has been a formidable task. However, now that the framework has been established, building upon this data base and discovering new ways to use this information will further accentuate the value of this final product. SCS Engineers envisions a number of uses for the WIRW data base, and the full potential of this system is yet to be realized.

RECOMMENDATIONS

Because of the data availability and accuracy status during this project, it is recommended that the WIRW data base be updated in about a year. At that time much relevant data, currently being developed, will be available. The update will be relatively efficient because of the data base availability.

There are several ongoing EPA projects which will facilitate estimating impact of discharges on surface waters and water supplies. Some of the most important are:

1. EPA, MDSD - Industrial Facility Discharge File (IFD) - will provide data on municipal and industrial discharge

TABLE 4. SOURCE WATER IMPACT ACCORDING TO POPULATION AND PERCENT WASTEWATER

State	City	Line	Source Water	Pop X1000	Percent Wastewater	
					Conservative(1)	Degraded(2)
PA	Philadelphia	155	Schuylkill R	1,950	3.5	2.5
SC	Columbia	259	Saluda R	228	16	9.8
PA	Bryn Mawr	149	Neshaminy Ck	820	3.8	3.5
IN	Indianapolis	464	White R	680	4.3	3.0
PA	Middletown	140	Neshaminy Ck	759	3.8	3.5
TX	Dallas	539	Lk Ray Hubbard	878	2.8	2.7
AL	Birmingham	207	Cabaha R	650	3.6	3.4
NJ	Elizabeth	166	Delaware-Raritan CA	500	4.3	3.9
MD	Baltimore	124	Susquehanna R	1,755	1.2	0.57
NJ	Little Falls	055	Passaic R	333	4.9	4.1
MO	St. Louis	381	Mississippi R	600	2.2	0.13
LA	New Orleans	525	Mississippi R	550	1.8	0.017
NJ	Millburn	054	Passaic R	234	4.8	4.2
OH	Cincinnati	447	Ohio R	850	1.3	0.20
LA	Marrero	524	Mississippi R	600	1.8	0.018
MD	Hyattsville/Wash DC	178	Potomac R	1,300	0.8	0.39
KY	Louisville	454	Ohio R	700	1.4	0.26
MO	Kansas City	359	Missouri R	750	1.2	0.22
TX	Fort Worth	538	Ben Brook Lk	490	1.6	1.4
MO	St. Louis	362	Missouri R	600	1.3	.04
CO	Pueblo	495	Arkansas R	95	7.6	5.3
SC	Rock Hill	266	Catawba R	426	1.4	0.71
NJ	Elizabeth	167	Raritan & Millstone	500	1.1	.95
IL	East St. Louis	382	Mississippi R	215	2.2	0.13
GA	Columbus	237	Lk Oliver	134	3.2	1.5

(1) Cumulative percent wastewater estimates under average source water flow conditions.
(2) Cumulative percent wastewater estimates using exponential degradation model.

locations, flows and activities (SIC codes) for over 40,000 dischargers. Complete March 1980.

2. EPA, MDSD - Hydrologic Digital File (Reach File) project - will provide data base on hydrologic structure and stream flows. Complete November 1979.

3. EPA, EGD - Development of screening data on priority pollutants in municipal and industrial effluents. - Some data available on most discharger categories, will improve as more data collected.

4. EPA, Enforcement - Permit Compliance System Modification - PCS file will be modified to include discharge permit limitations for all major dischargers - Complete January 1980.

5. EPA, MDSD - Priority Pollutant Fate - will provide data on physical properties of priority pollutants to estimate degradation rates and fates. Complete April 1979.

6. EPA, ORD - Proposed Ambient Water Quality Criteria - will provide water quality criteria for priority pollutants based on aquatic toxicity and human health effects. Draft criteria available.

A procedure which could be used is as follows:

1. Update the WIRW data base using discharge locations and flow data from the IFD file.

2. Update the WIRW data base using hydrologic structure and stream flows from Reach file.

3. Add pollutant limitations to WIRW data base using limitation data from modified PCS file.

4. Operate the WIRW to produce estimates of mass loadings of pollutants.

5. Modify mass loadings derived from step 4 by fate data to estimate instream concentrations due to upstream discharges.

6. Compare instream concentrations to criteria established to determine high impact areas.

7. Use WIRW system to determine causes of high impact.

This procedure, which can be efficiently started in about one year, should provide more information on which to base decisions regarding relations between dischargers and water supply systems.

SANTA CLARA VALLEY WATER DISTRICT'S WATER RECLAMATION FACILITY AT PALO ALTO

Lloyd C. Fowler
Chief Engineer
Santa Clara Valley Water District

Santa Clara Valley Water District is the water management agency for Santa Clara County which is located at the southern end of San Francisco Bay. The eastern and western boundaries are crests of mountain ranges. The northern half of the 3,100 square kilometre area drains to San Francisco Bay and the southern half to Monterey Bay.

The District currently (1978) uses about 460 million cubic metres of water a year, essentially equal to the available water supplies.(1) Based on past trends, the need for water is expected to increase to about 920 million cubic metres per year by the year 2020; however, reduced population growth trends could bring this projection down to about 800 million cubic metres per year. The District has initiated a water savings and reuse program by which it hopes to reduce these projected needs for water. An intensive water awareness education curriculum is being implemented in the local schools to develop a new generation of careful water users. By this means, the future water needs should be reduced by 10% or more to about 720 million cubic metres per year.

In addition to water savings, the District expects water reuse to play an important part in reducing the need for importing additional water. Currently one-third of the water supply is imported. The rest of the water supply is almost entirely from groundwater. The local supplies are highly developed and the most economical supplemental water supply is importation. In the belief that water reuse will be a viable supply for domestic water needs, contracts for additional imported supplemental water have been reduced by about 25 million cubic metres per year from that believed necessary to meet the 2020 water needs. This amount is expected to be furnished by reclaimed water. The contracts have provisions to allow the import of this amount of water if reclamation is found not to be a viable source of supplemental domestic water service.

The question is can reclaimed water be a source for domestic water service? From a technologic standpoint, wastewaters can be treated to more than meet the current drinking water standards. But the public health authorities say no to the use of reclaimed water for domestic use. They cite the concerns over virus transmission, organic chemicals that may cause cancer or mutations, inorganic chemicals that may accumulate in body tissues enough to become toxic, and the apparent lack of reliability of wastewater treatment plant operation. Therefore, the Santa Clara Valley Water District decided to construct an advanced wastewater treatment facility to attempt to demonstrate the viability of water reuse.

The northern portion of the District borders on San Francisco Bay. The deeper heavily pumped freshwater aquifers are separated from the saline bay waters by extensive layers of fine sediments. The shallow aquifers are not. The best use of the groundwater basin requires that water levels be drawn below sea level thus inviting seawater intrusion. Such intrusion has occurred in the shallow aquifers. These saline waters could move further inland, reach holes or discontinuities in the underlying fine sediments, and cascade vertically downwards to the lower aquifers. This has happened in the Alameda County part of the San Francisco Bay groundwater system. A barrier to the movement of saline water in the shallower aquifers would prevent this.

There are only two types of barriers that could be used. These are a physical wall formed of sheet piling, slurry trench, or injected cement or chemical grout, and a hydraulic barrier. Since the barriers could be required to depths up to 200 feet, the physical barriers were not practical from a cost standpoint. The hydraulic barrier could be created in the intruded zones at whatever depth necessary and could be either an extraction trough or an injection mound or a combination of both. In the case of the extraction trough, all the intruding saline water would have to be extracted. This would also cause withdrawal of fresh groundwater from the inland side which would move into the trough. The extracted water would be too saline for use and would have to be disposed of. The injection mound would raise the hydraulic grade line of the groundwater system above sea level and block the further intrusion of saline waters. However, in areas near the Bay, this could require hydraulic grade line elevations at or above the ground elevations. Such areas could become waterlogged. In order to minimize such potential problems, it was decided to use a combination of injection and extraction. Injection would create a barrier to seawater intrusion and extraction inland of the injection barrier would keep the hydraulic grade line down, remove the saline water inland of the injection point, and after the saline water was removed, it would be a source of freshwater primarily from the injection wells. This injection-extraction system was selected to repel saltwater intrusion in the Palo Alto area of the District.

A hydraulic barrier requires a supply of water. While not too much freshwater would be required, some would be lost to the bay and some to the initial mixing with the inland saline wedge as it was removed. Since existing supplies of freshwater were expensive and limited in amount, it was decided to use waters reclaimed from the wastewaters being discharged to the Bay. The Palo Alto area was selected for the initial barrier location because of known saline intrusion near the wastewater treatment plant and portions of the old treatment plant abandoned when the new one was constructed could be used for the additional treatment necessary.

The new wastewater treatment facility serves the communities of Mountain View, Los Altos, and Palo Alto. It provides primary and secondary treatment using an activated sludge process. Its capacity is 1.5 cubic metres per second. The portions of the old plant abandoned were a vacuum flotation unit, a primary clarifier, and a primary digester. These units were given to the District by the Tri Cities Regional Sewage Agency for conversion and the land leased for a minimal amount. The City of Palo Alto, which operated the new wastewater treatment facilities, agreed to operate the water reclamation facility at cost and charge $5,000 per year for sludge disposal in their incinerator.

The District's consultants, Jenks and Harrison of Palo Alto and Brown and Caldwell of San Francisco, designed the 0.2 cubic metre per second reclamation facility and the injection-extraction well field, respectively. The conversion of the abandoned units required considerable ingenuity and piping extension, but resulted in considerable cost savings to the project. The pre-aeration chamber ahead of a vacuum flotation unit (vacuator) was converted to a flash mixing chamber for combining lime slurry with incoming secondary effluent. The circular Vacuator structure was converted into a mixed (tri) media filter. The primary clarifier was converted into a combined flocculator-clarifier for lime floc formation and settling. The primary digester tank was converted into two reclaimed water storage cells by a new concrete wall.

The design of the water reclamation facility was awarded the Excellence in Engineering Design Award for 1979 by Water and Wastes Engineering(2) for the unique conversion of old facilities, thereby reducing the project costs, and inovative uses of known principles in the advanced wastewater treatment processes.

The treatment process allows for direct filtration of secondary effluent for use as irrigation water. This reduces the cost of operation when other uses requiring full tertiary treatment do not need water. The full treatment process includes:

- Chemical flash mixing, flocculation, and sedimentation using lime as the primary coagulant.

- Aeration by blowers and floating spray fountains to help remove ammonia and other volatiles. These units remove enough ammonia to significantly reduce chlorine requirements for final stage ammonia removals by breakpoint chlorination.

- Recarbonation using stack gases from the sewage treatment plant sludge incineration unit for pH adjustment.

- Ozonation to oxidate soluble organics and provide initial disinfection.

- Mixed-media filtration provides further suspended solids removal. These units can be used both before and after the activated carbon adsorption towers to prolong the carbon life and reduce the carryover of carbon fines to the injection wells.

- Activated carbon adsorption for removal of dissolved organics, chlorinated hydrocarbons, and trace heavy metals.

- Chlorination for final sterilization.

Evaluation of instrumentation and control alternatives showed that use of a computer system for both data logging and control of the reclamation project was less costly than conventional instrumentation. The process control computer takes data to and from over 400 analog and digital data points on a variable one to ten second frequency providing control, display, alarm, and logging of plant process and well operation. Currently, the plant operation is manually supervised eight hours a day and operated by computer 16 hours a day and 63 hours on weekends. The alarm module can initiate and complete process shutdown under selected alarm conditions.

The treatment process was dictated by the need to produce a water suitable for injection into the underground through wells. This requires water free of dissolved gases, with zero turbidity (suspended solids), and sterile. Water-bearing aquifers are easily plugged by suspended solids and gas bubbles. Gas bubbles are generated by changes in pressure and temperature as the water is injected into the aquifer. Neither gas bubbles nor suspended solids lodged in aquifer materials can be successfully removed by normal well redevelopment means, and the aquifer becomes plugged refusing to accept additional injection water. Bacterial growths, especially of slimes, can occur in wells and in the aquifers if the injected water is not fully sterilized. These growths are very effective in plugging injection wells.

The plant design allows bypassing of and alternative flow paths between the various treatment processes. This was done to allow the maximum flexibility in the treatment process sequences to obtain a desired quality of water at the lowest costs. It also will allow the testing of the various processes to determine what changes in water quality occur in each and what sequences of processes are needed to produce a quality of water suitable for domestic water service.

The water reclamation facility is intended to produce a useable water. Water produced is being used for irrigation of a golf course and landscaping. Proposed market expansions include industrial uses such as cooling and washing. Besides these direct uses, research is programmed to determine whether or not water suitable for domestic use can be produced. Water quality changes through the various treatment processes are being examined by automated water quality monitoring units developed by the National Aeronautics and Space Administration. Similar changes in quality of injected water as it travels in saturated aquifers are being examined by Stanford University. The total objective is to demonstrate plant reliability and water quality change capability of the processes involved.

It does not appear possible to demonstrate continued reliability for reuse until water quality characteristics of the reclaimed water can be presented on a real-time basis. The NASA Johnson Space Center developed a real-time water quality monitoring unit which was transferred to NASA Ames Research Center in Mountain View in June 1977. This unit has been in operation at the water reclamation facility since Sept. 1977 and has demonstrated the viability of real-time water quality monitoring. It currently monitors and displays 17 water quality parameters: sodium, nitrate, total oxygen demand, total organic carbon, turbidity, dissolved oxygen, pH, chloride, ammonia, conductivity, temperature, residual chlorine, hardness, total biomass, viable biomass, total coliform, and halogenated hydrocarbons. Most of the sensors used are commercial units, but the biosensor, coliform, and gas chromatography sensors were developed by NASA.(3) The biosensor utilizes the luminol-carbon monoxide method for monitoring total viable and nonviable biomass in water. The coliform sensor detects total or fecal coliform organisms by measuring the time required for hydrogen production from lactose metabolism using hydrogen specific electrodes.

Existing gas chromatograph methodology was adapted for rapid in-situ analysis for halogenated organic compounds at the part-per-billion level in water. NASA Ames is working on a viral detector to be added to the water quality monitoring unit. A series of mini computers handle all sampling details, sensor calibration, and output conversion, data analyses storage and displays, and report outputs.

Water quality changes can be expected to occur in injected water as it travels underground as a result of adsorption, ion exchange, precipitation, dissolution, oxidation, etc. Researchers at Stanford University are evaluating these changes in the saturated zone near one of the injection wells. They have found that the travel times for ammonia nitrogen, trace metals, such as Cu and Cd, and a large number of trace organic compounds were greatly in excess of the travel time for the injection front to move from the injection well to an observation well(4).

Planned further activity at the water reclamation facility includes computer control of chemical feed and treatment process train selection based on real-time water quality data. It is believed that effluent quality reliability can be improved by computer operation as real-time water quality data is made available.

The District's water reclamation facility at Palo Alto provides reclaimed water for irrigation and a seawater intrusion barrier. The reuse of water is expected to be extended to industrial uses as the distribution system is extended. Besides providing a supply of water, the objectives of the water reclamation facility include the demonstration of reclamation plant reliability and water quality acceptability for all uses.

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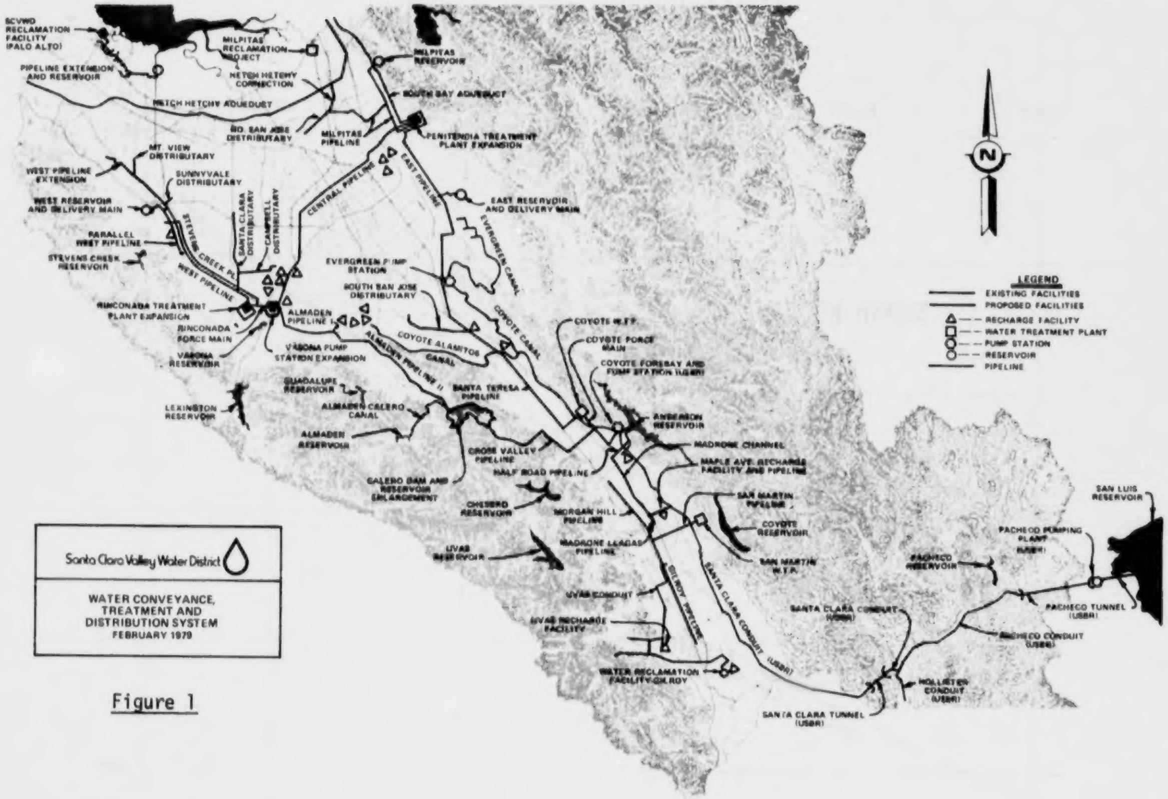


Santa Clara Valley Water District

WATER CONVEYANCE,
TREATMENT AND
DISTRIBUTION SYSTEM
FEBRUARY 1979

Figure 1

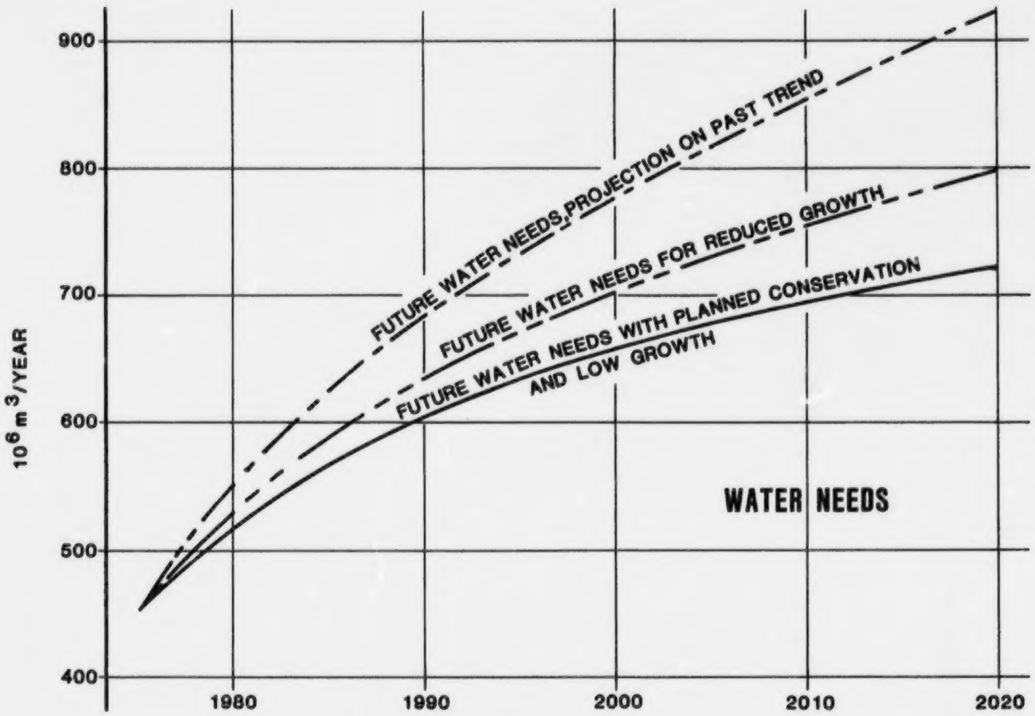
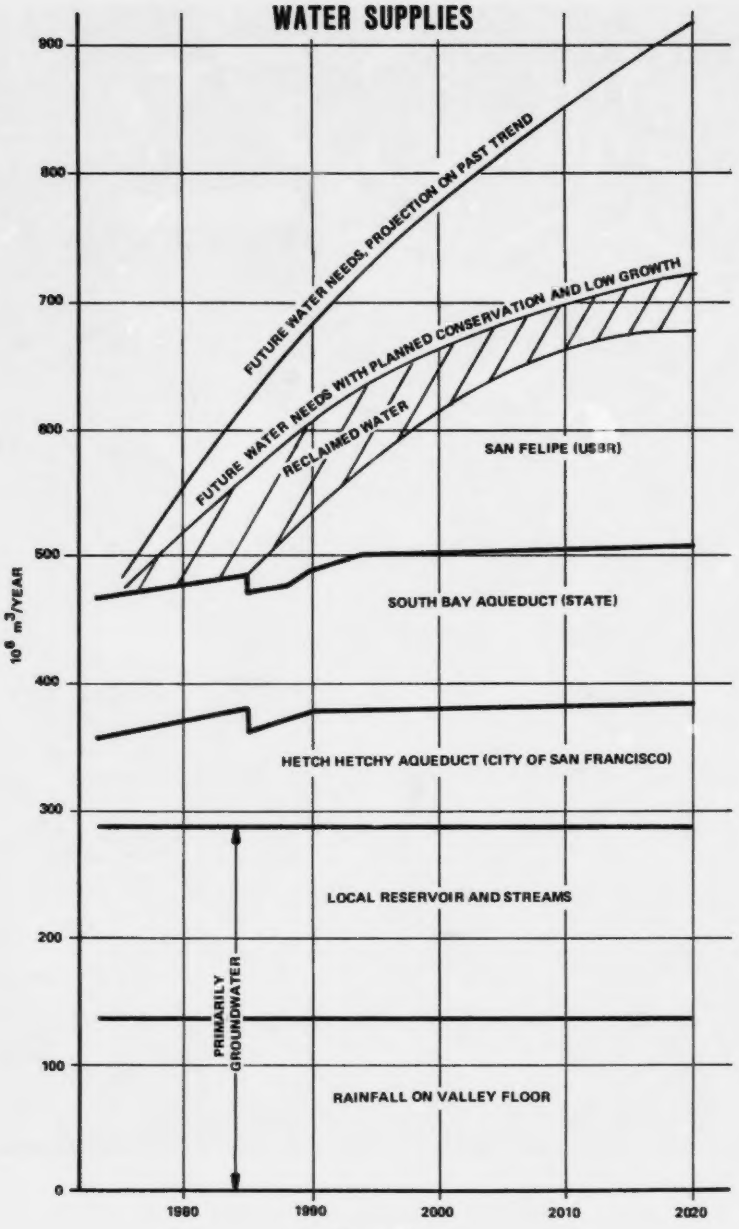

WATER NEEDS
FUTURE WATER NEEDS PROJECTION ON PAST TREND
FUTURE WATER NEEDS FOR REDUCED GROWTH
FUTURE WATER NEEDS WITH PLANNED CONSERVATION AND LOW GROWTH
10^6 m^3/YEAR
900
800
700
600
500
400
1980
1990
2000
2010
2020

Figure 2


WATER SUPPLIES
FUTURE WATER NEEDS, PROJECTION ON PAST TREND
FUTURE WATER NEEDS WITH PLANNED CONSERVATION AND LOW GROWTH
RECLAIMED WATER
SAN FELIPE (USBR)
SOUTH BAY AQUEDUCT (STATE)
HETCH HETCHY AQUEDUCT (CITY OF SAN FRANCISCO)
LOCAL RESERVOIR AND STREAMS
PRIMARILY GROUNDWATER
RAINFALL ON VALLEY FLOOR
10^6 m^3/YEAR
900
800
700
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500
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100
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1980
1990
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2010
2020

Figure 3

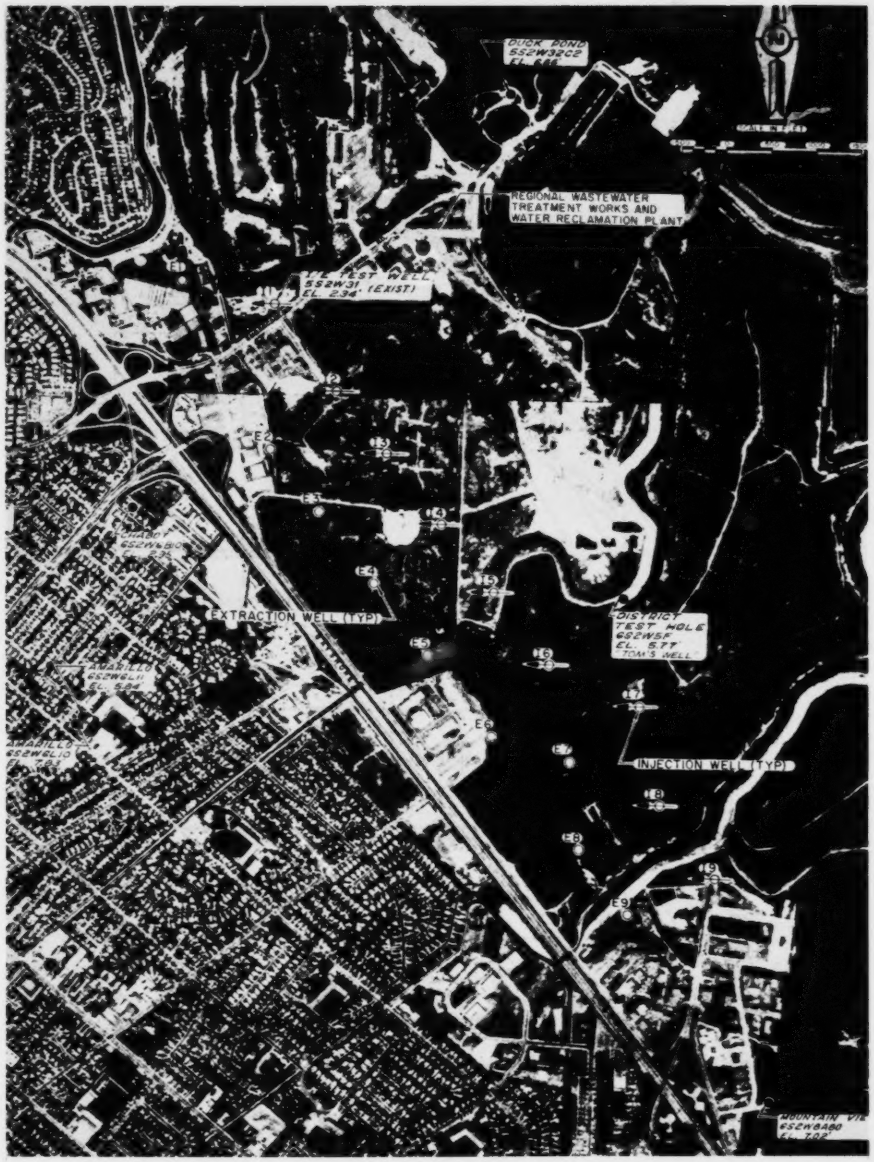
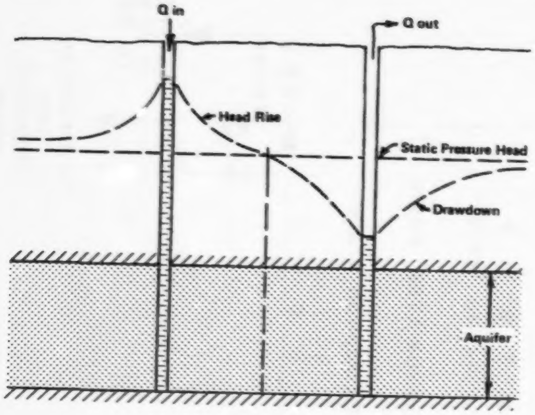
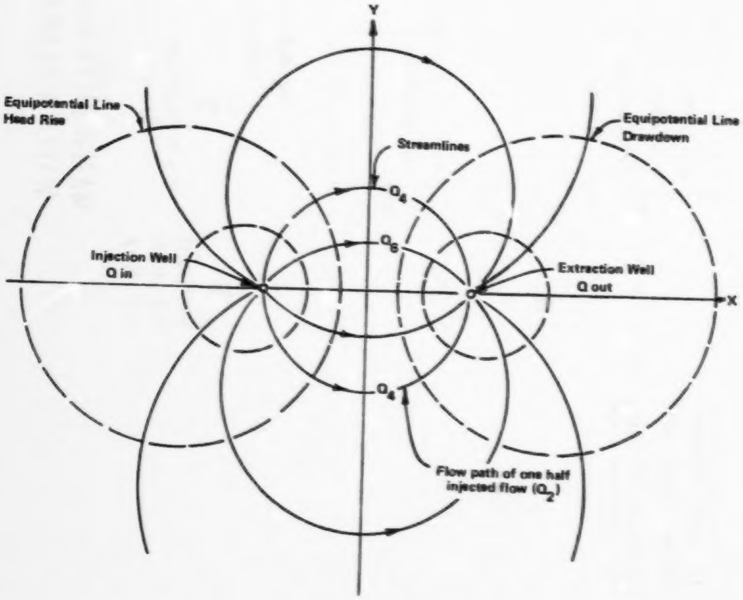


FIGURE 4

Injection-Extraction Well System



SECTION



PLAN

Figure 5

INJECTION-EXTRACTION WELL PAIR

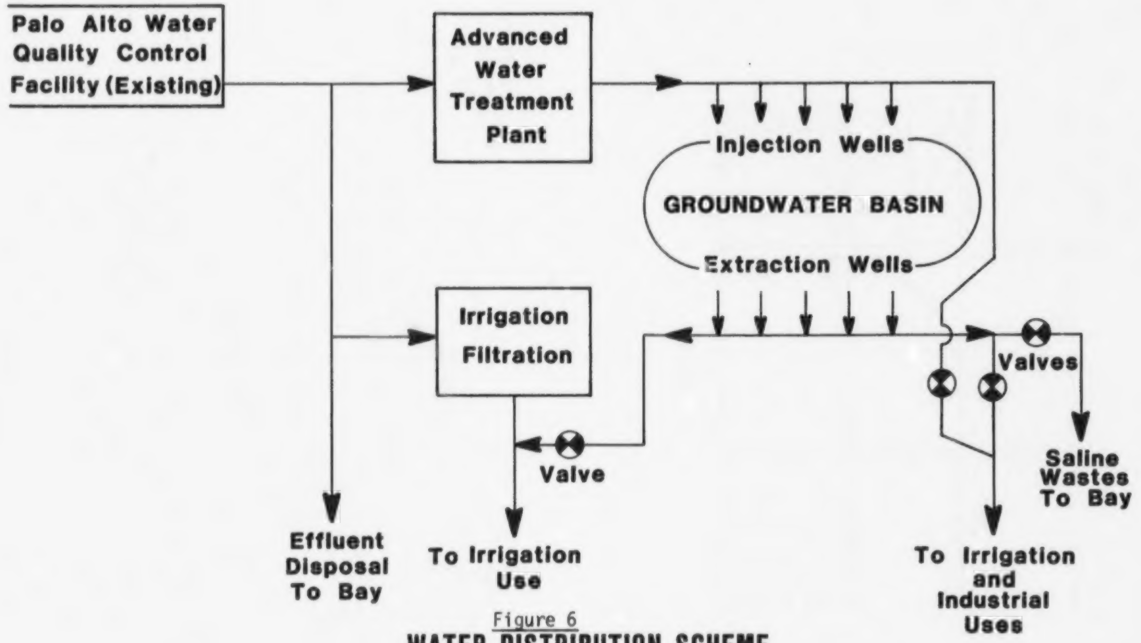


Figure 6
WATER DISTRIBUTION SCHEME
WATER RECLAMATION PLANT

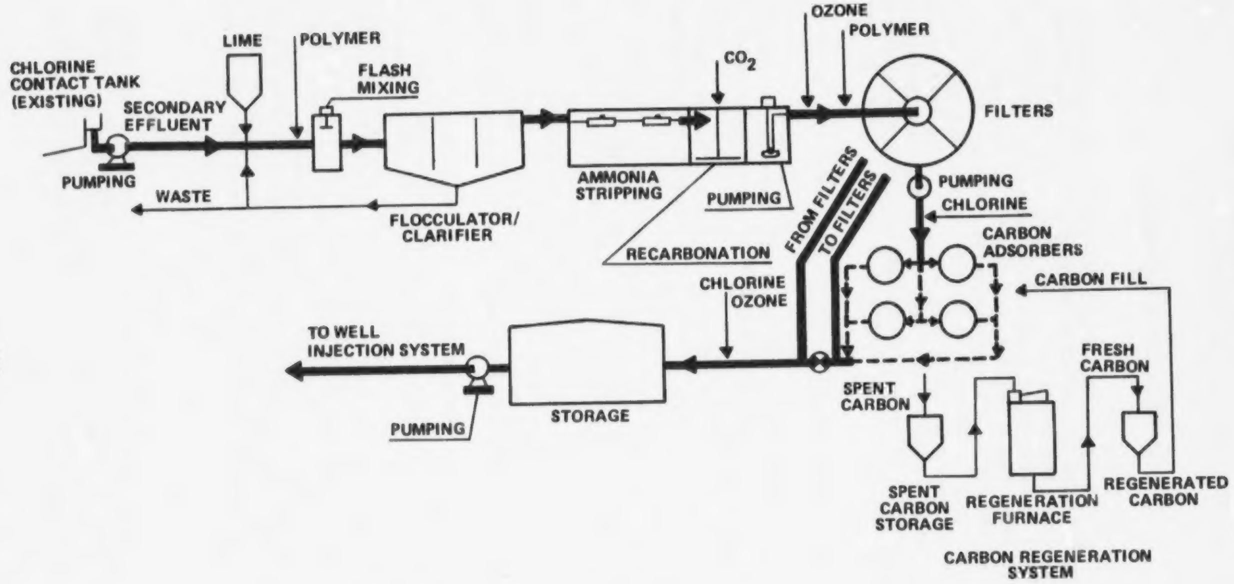


Figure 7

BASIC PROCESS FLOW DIAGRAM

"SITING OF WATER INTAKES DOWNSTREAM FROM MUNICIPAL WASTEWATER FACILITIES"

BY

PATRICK TOBIN AND GEORGE WESNER*

The purpose of this study was to present information and guidelines relevant to the location of surface water supply intakes downstream from municipal wastewater discharges. The study makes no attempt to provide standards or rules to be used in all situations. Decisions on the location of water supply intakes must be made by informed professionals at the local level after careful consideration of all factors and this study is intended to provide information that will be useful to local professionals and review officials. The data required for evaluating intake location, available stream modeling techniques, capability and costs of water and wastewater treatment processes and the public health implications of upstream wastewater discharges are reviewed.

PROJECTING RAW WATER SUPPLY QUALITY

The many natural and human factors which affect stream water quality cause large variations in the concentrations of trace contaminants as well as constituents commonly found in waters such as chloride, sulfate, calcium, and sodium. Variations can occur within relatively short distances in streams and such variations often occur in an unsystematic and nonpredictable manner. The concentrations of contaminants in streams are affected by reactions such as precipitation, complexation, oxidation-reduction, ion exchange, adsorption and/or desorption, flocculation, and biological uptake and/or release. Stream physical characteristics which affect of fate of contaminants include velocity, depth, turbulence, degree of mixing, temperature, turbidity, changes in cross section and bottom characteristics such as slope, type of material and sorptive capacity. The effects of some of these parameters are so interrelated that their relative importance is difficult to determine.

Despite the complexity of surface water systems, mathematical models have been developed which provide useful insights into the fate of various contaminants. The models generally fall into three categories: (1) steady-state models in which the variables involved are unchanging with time, (2) dynamic-equilibrium models that vary with time but only in a cyclically repetitious manner, and (3) dynamic models in which the inputs and outputs may vary freely with time. Available models are briefly described and their limitations and data requirements are presented. All of the models contain constants that deal with dispersion, sorption, reaeration and diffusion rates. The values of these constants should be obtained through experimental work for the river basin being modeled.

* Mr. Tobin is a Physical Science Administrator, Office of Drinking Water, Environmental Protection Agency and Dr. Wesner is a partner with Culp/Wesner/Culp, Consulting Engineers, El Dorado Hills, California. Presented at the International Water Reuse Symposium, Washington, D.C., March 26, 1979.

The U.S. Geological Survey operates a water quality network that obtains data from 345 stream monitoring stations in the United States. The Environmental Protection Agency (EPA) has recently completed a survey of the quality of raw water supplies, including 35 surface supplies, to determine the presence of trihalomethanes and the effects of water treatment processes. The study found that 35 surface supplies had a median chloroform concentration of less than 0.2 ug/l and that chlorination of these supplies resulted in formation of trihalomethanes. Based on a review of the data collected in the EPA survey and other available surface water data, the following typical background stream concentrations of organics were selected for analyzing the effects of wastewater discharges on downstream water supplies: biochemical oxygen demand (BOD) = 5 milligrams per liter (mg/l); chemical oxygen demand (COD) = 30 mg/l; total organic carbon (TOC) = 10 mg/l.

With the exception of turbidity and coliform bacteria, most raw surface supplies do not exceed the National Primary and Secondary Drinking Water Regulations. Although secondary municipal effluents also do not normally exceed Drinking Water Regulations limits for inorganic chemicals, they do contain turbidity, organic compounds, and pathogens of concern in downstream water supplies. Trace organics are the most important concern because of their largely unknown long term health effects in drinking water.

The public policy adopted by EPA's Office of Drinking Water has been that the Drinking Water Regulations are applicable to tap water whose water supply source is relatively free from pollution. This public policy is further interpreted by the public health agencies that these standards are not comprehensive for determining the adequacy for the reuse of municipal wastewaters for potable purposes. This policy is based upon public health prudence. Until scientific evidence can assure that there is no present or potential health effect from the use of wastewaters for potable purposes, this public policy will probably continue.

CAPABILITY OF TREATMENT PROCESSES FOR CONTAMINANT REMOVAL

Several levels of wastewater and water treatment may be used to achieve varying removals of the contaminants specified in the Drinking Water Regulations. These contaminants are divided into the following categories: microbiological, turbidity, organic chemicals, inorganic chemicals and radioactive materials.

Microbiological - Conventional wastewater treatment processes (primary and biological secondary treatment plus chlorination) may achieve at least 90 percent reductions of virus and bacteria but cannot provide a completely disinfected effluent. Conventional water treatment and advanced wastewater treatment (AWT) processes such as chemical clarification, and filtration coupled with chlorination or ozonation can provide complete removal of viruses and coliform bacteria.

Turbidity - Modern water treatment methods can routinely produce water to meet the drinking requirements for turbidity. Typical secondary effluent turbidities of 10-30 turbidity units (TU) can be reduced to 0.1 - 1.0 TU by AWT processes.

Organic Chemicals - Some trace organics, many of which are by-products of the chlorination process, are potential carcinogens. In general, the formation of these compounds can be minimized by chlorinating at the point in the water treatment process with the highest quality water. Other control methods include: (1) use of disinfectants which do not generate trihalomethanes, (2) treatment to reduce precursor concentration prior to chlorination, and (3) treatment to reduce the trihalomethane concentrations after formation.

Typical secondary effluent COD levels of 60-100 mg/l have been reduced to as low as 3 mg/l by AWT processes, including granular activated carbon adsorption. However, COD values of 10-12 mg/l appear to represent a more practical level achievable in full-scale, continuous treatment of municipal wastewaters. Reverse osmosis treatment of effluent from the carbon adsorption process can reduce the COD level to 1 mg/l or less in both water and wastewater treatment systems.

Inorganic Chemicals - Chemical clarification is the most generally applicable method for removal of inorganic chemicals in water and wastewater treatment systems. Although toxic inorganic chemicals are not normally present in raw surface waters or municipal secondary effluent, in concentrations that exceed the Drinking Water Regulations, there exists treatment technologies for specific water and wastewater unit processes for removal of arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, silver, copper, iron, manganese, zinc, hardness and total dissolved solids.

Radioactive Material - Radioactive materials are not normally present in surface water supplies or municipal wastewaters at levels that exceed the Drinking Water Regulations. Treatment of water containing radioactive materials may present special problems that are not considered in this report.

FACTORS IN LOCATING WATER INTAKES

Exclusive of wastewater discharges, there are many factors to be considered in locating an intake, such as, quality difference between potential sources, adequacy of quantity, accessability, siltation potential, navigation needs, flood levels and foundation conditions. Rural and urban runoff and accidental spills can contribute to public health problems even in the absence of upstream wastewater discharges and intake locations should be selected to minimize these potential problems.

There is a lack of raw water quality standards applicable to both polluted water supply sources and to relatively unpolluted sources on which drinking water regulations are now based. This lack causes many uncertainties for water supplies downstream of wastewater discharges when such discharges constitute a significant portion of the supply. Although there are many water plants which now produce biologically safe drinking water from streams and rivers containing substantial amounts of wastewater, there is uncertainty about the long term effects of the organic materials which may survive both natural purification processes in the stream and water and wastewater treatment processes. Current standards or inorganic compounds appear adequate. Although there are questions about the adequacy of the coliform bacteria standards, experience has indicated that there have been few waterborne disease outbreaks in communities with water supplies meeting coliform standards. Standards for organics are the greatest unanswered questions.

Of great practical importance is the effect that wastewater discharges have on the distance that should be maintained between an intake and the wastewater discharge. Clearly, some significant separation should be provided to take advantage of natural purification process and to allow time for adequate monitoring and detection of upstream wastewater plant malfunctions. It appears that at least 24 hours of combined time in travel and storage should be provided to allow for reaction time to emergencies. Greater separation to allow more treatment through natural processes may or may not be more economical than equal removal by improved treatment. Many toxic materials are not effectively removed by natural processes and added separation provides more time for die-off of pathogens but complete removal of pathogens can be provided by treatment processes. Time of stream travel probably has little effect on any health hazards from synthetic organics.

Several studies document the fact that wastewater treatment plants often do not operate at their design efficiency. Such inefficiencies or periodic failures may be particularly significant to downstream water supplies. Conventional plant designs can be modified to greatly increase reliability, although at increased cost.

ALTERNATIVES IN WATER INTAKE LOCATIONS

In order to compare the effects of several variables that must be considered when evaluating potential water intake locations, a wastewater discharge--water intake and supply model system was established. The system variables include: (1) level of wastewater treatment (2) separation time between the point of wastewater discharge and the water intake, (3) quantity of wastewater as a percentage of total stream flow, (4) level of wastewater treatment, and (5) relative sizes of the wastewater and water treatment plants. In addition to secondary wastewater treatment, AWT (including lime clarification, filtration, and carbon adsorption) was considered. Levels of water treatment considered were "conventional," (upgraded chemical clarification, mixed media filtration and granular carbon adsorption), and "upgraded plus reverse osmosis."

The following average organic concentrations and percentage removals are used in the cases evaluated:

	Concentration, mg/l			Percentage Removal		
	BOD	COD	TOC	BOD	COD	TOC
Stream Flow	5	30	10	--	--	--
Effluents						
Secondary	30	100	40	--	--	--
Advanced Wastewater Treatment	2	20	8	93	80	80
Conventional Water Treatment	1	10	5	80	67	50
Upgraded Water Treatment	None	2	1	100	93	90
Upgraded Water Treatment & Reverse Osmosis	None	1	1	100	97	90

A detailed analysis of the unit costs for the various treatment processes was conducted. The Summary Table presents the costs and finished water qualities of a Base Case and either other cases for different combinations of treatment. The following general conclusions can be derived from the data summarized in the table:

1. Given the alternatives of providing AWT upstream of a conventional water treatment plant (Case 4) or continuing secondary treatment and instituting upgraded water treatment (Case 1), it is significantly lower in cost to upgrade the water treatment plant rather than the wastewater plant. This alternative (Case 1) also produces higher quality finished water. The larger the wastewater plant in relation the the water treatment plant, the more significant are the savings.

2. Upgrading the water treatment plant, even with effluent from a secondary plant 1-day upstream (Case 1) constituting 20 percent of the stream flows, results in higher finished water quality than would be produced by conventional treatment of typical stream water without a nearby municipal effluent discharge (see footnote 3 in Summary Table).

3. Upgrading the level of water treatment (Case 1) results in only a 2 to 14 percent increase in the Base Case wastewater plus water treatment costs but a very significant improvement in finished water quality.

4. Effects of the wastewater discharge on the ecosystem in the stream, eutrophication potential, and aesthetic considerations are more pertinent to whether secondary or advanced wastewater treatment should be provided than is the effect on quality of the downstream water supply.

An analysis of the costs to provide increased wastewater and water treatment plant reliability was also made. To provide essentially 100 percent reliability with standby treatment units and standby power, the total annual costs for wastewater treatment would increase by about 25 percent at 5 mgd and 13 percent at 25 and 50 mgd; the costs for water treatment would increase by 19 percent at 5 mgd, 8 - 12 percent at 25 mgd, and 4 - 8 percent at 50 mgd.

CASE HISTORIES

Three instances involving wastewater discharges above water supply intakes were reviewed. These case histories are included to illustrate the judgements that were made by local officials in evaluating the merits of each case. In one case, Occoquan, Virginia, the evaluation is still in progress.

Occoquan, Virginia - Several small secondary wastewater plants discharged their effluent for several years into the Occoquan Reservoir, a water supply reservoir for the Washington, D.C. area. The reservoir became highly eutrophic with the secondary effluents identified as the primary cause. It was expected that wastewater flows would eventually constitute 12 percent of the annual inflow to the reservoir and 46 percent of the July low flow. The alternative of exporting the secondary effluents below the water intakes was proposed but encountered public and agency opposition, primarily due to the high cost. A study of the State Water Control Board (SWCB) concluded that with AWT and continued discharge to the reservoir, the quantities of pollutants would be significantly reduced even at wastewater flows 10 times those than being experienced. The AWT alternative also offered substantial cost savings over the export alternative. The downstream water utility and the State Department of Health initially opposed this plan because of the concerns about viruses; however, a supplemental review by the SWCB of the virus issue caused the opposition to be dropped. The SWCB adopted a policy calling for abandoning the 25 secondary plants in the basin and for AWT in a regional 10 mgd plant with discharge of the effluent to the water supply reservoir. The rigid weekly average effluent quality requirements include: BOD = 1 mg/l, COD = 10 mg/l, suspended solids = 0 mg/l, nitrogen =1 mg/l, phosphorus = 0.1 mg/l, and coliform bacteria less than 2 per 100 milliliters. The policy requires specific treatment processes and backup treatment units to insure reliability. Regional review agencies concluded that the travel distance of 20 miles (travel time of 100 - 190 days) and effective downstream water treatment were adequate. The regional AWT plant began operation in early 1978.

Huron River, Michigan - In this case involving the Huron River, a 41 mgd wastewater discharge (nitrified, filtered effluent), was proposed about 14 miles upstream of the 4 mgd Flat Rock, Michigan water treatment plant. An environmental assessment concluded that at 7 day, 10 year dry flow conditions, the nitrate concentration in the Huron River would reach 10.25 mg/l, which is 0.25 mg/l above the drinking water standard, due to the wastewater discharge. The assessment also concluded that the combination of discharge organic material and chlorination could cause taste and odor problems. The wastewater flow constituted nearly 40 percent of the 7 day, 10 year dry flow. Any plant malfunctions were expected to cause serious water quality problems at the water intake and pose the threat of inadequately disinfected finished water. The Michigan Department of Health stated that if the wastewater project proceeded, the Flat Rock water plant would no longer be permitted to use the Huron River as a supply and the funding of an alternative supply for Flat Rock, including retirement of the existing bonds, should be included in the cost of the wastewater project. The proposed wastewater project was abandoned.

Passaic Basin, New Jersey - There are some 115 municipal and industrial waste discharges totaling 50 mgd, which constitutes about 60 percent of the flow at the Little Falls water supply intake for a 100 mgd plant serving 15 northern New Jersey communities. The water plant utilizes conventional treatment with powdered carbon additions during times of particularly poor water quality or upstream waste spills. The water utility admittedly depends upon the wastewater discharges to meet its quantity requirements. Although one of the most polluted rivers in the east, the Passaic is still serving satisfactorily as a major water supply. No viral diseases have been traced to the water supply. One of the main concerns of the water utility is the potential for significant trihalomethane concentrations. Consideration is being given to construction of granular carbon filters at the water treatment plant and use of AWT upstream, however, no firm decisions have been made at this time.

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SUMMARY TABLE

TOTAL COST AND WATER TREATMENT PLANT PRODUCT WATER QUALITY

Case	Level of Wastewater Treatment	Level of Water Treatment	Separation Time (Days)	Wastewater Treatment plus Water Treatment Costs ($/1,000 gallons water produced)			Water Treatment Plant Product Water Quality[3] (Concentration, mg/1)					
				50 mgd WWTP & 5 mgd WTP[2]	5 mgd WWTP & 50 mgd WTP	25 mgd WWTP & 25 mgd WTP	For 20% Wastewater Reuse[4]			For 5% Wastewater Reuse[4]		
							BOD	COD	TOC	BOD	COD	TOC
Base	Secondary	Conventional	1.0	3.30	0.191	0.526	2	14	8	1.2	11	5.8
1	Secondary	Upgraded	1.0	3.36	0.217	0.560	ND	3.1	1.6	ND	2.3	1.2
2	Secondary	Upgraded plus Reverse Osmosis	1.0	4.01	0.785	1.15	ND	1.3	<1.6	ND	1.0	<1.2
3	Secondary	Conventional	2-30[1]	3.34	0.192	0.530	2	14	8	1.2	11	5.8
4	Advanced	Conventional	1.0	6.62	0.250	0.906	0.9	9.2	4.8	1.0	9.7	5.0
5	Advanced	Upgraded	1.0	6.67	0.277	0.940	ND	2.0	1.0	ND	2.1	1.0
6	Advanced	Conventional	2-30[1]	6.65	0.251	0.911	0.9	9.2	4.8	1.0	9.7	5.0
7	Advanced	Upgraded	2-30[1]	6.71	0.277	0.944	ND	2.0	1.0	ND	2.1	1.0
8	Advanced	Upgraded plus Reverse Osmosis	2-30[1]	7.37	0.845	1.54	ND	0.8	<1.0	ND	0.9	<1.0

[1] Costs are included for 1-day storage at the wastewater treatment plant.

[2] WWTP = Wastewater Treatment Plant, WTP = Water Treatment Plant, ND = None Detected.

[3] With no nearby upstream wastewater plant and with the assumed background stream quality, the water treatment plant product quality would be BOD <1 mg/1, COD = 10 mg/1, and TOC = 5 mg/1.

[4] Represents 20 percent or 5 percent of wastewater in total stream flow at the water intake.

OBSERVATIONS ON THE START-UP OF THE WATER RECLAMATION-RECHARGE PROJECT IN NASSAU COUNTY, N.Y.

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HISTORY OF THE PROJECT

Nassau County is one of four counties located on Long Island, New York. The counties of Kings (Brooklyn) and Queens are a part of New York City and are located to the West of Nassau County, while Suffolk County is located to the East. Although a ground water aquifer underlies all of Long Island, only Nassau and Suffolk Counties utilize this aquifer as their only source of potable water. For this reason, the Environmental Protection Agency recently declared this aquifer as a "Sole Source Aquifer".

The increased urbanization of Nassau County (present population is 1,480,000) after World War II has been accompanied by increased ground water pumpage and the contamination of the upper glacial aquifer. In order to retard the contamination of the glacial aquifer and to protect the remaining aquifers (the Magothy and the Lloyd), Nassau County embarked upon a sewering program in the early 1950's, which when completed in 1985 will result in the sewering of greater than 85% of Nassau County. The sewage effluent from the treatment facilities constructed as part of the sewering program is discharged to marine surface waters after undergoing secondary treatment.

The effect of the sewering program, together with the increased ground water pumpage, has been a net decline in the water table which has resulted in a decrease in freshwater streamflow (6), increased bay salinity, and the local landward movement of salty ground water (3,7). The effects of the declining water table have provided Nassau County with the need to study methods of replenishing the ground water aquifer in an effort to offset these effects. For this reason, reuse and recharge has been investigated in Nassau County since 1963 as follows:

1. 1963 - A Greeley and Hansen Report (8)recommended that Nassau County initiate research into water reclamation

and ground water recharge with emphasis on the construction of a hydraulic dam to retard salt water intrusion.

2. 1968 - After a series of bench scale studies were completed to provide the basis for the design of a pilot facility, the 400 gpm Water Renovation Plant and 500 foot deep injection well were placed into operation at Bay Park. The Nassau County Department of Public Works was responsible for the operation of the reclamation facilities while the United States Geological Survey (USGS) was responsible for the operation of the 500 foot recharge well. The result of the operation of this facility, which was terminated in April 1973, was that while water reclamation was feasible, deep well injection was not. This result was due to the fact that recharge took place into the relatively fine Magothy aquifer and was accompanied by a long-term well clogging rate of 3 feet of excessive head build-up per 1,000,000 gallons of injected water. (9) This excessive head build-up indicated that frequent redevelopment of the well was necessary to maintain a practical injection specific capacity.

3. 1971 - A second Greeley and Hansen Report (4) recommended that Nassau County adopt means of supplementing its ground water supply. The alternatives suggested include:

a) Import water from Suffolk County.
b) Import water from Upstate New York water resources.
c) Water renovation and ground water recharge.

This report summarized investigations of the USGS and the Nassau County Health Department, which indicated that salt water intrusion was not a major concern and that nitrate contamination in the central part of Nassau County was a more serious problem. The report recommended the upland recharge of 92 million gallons per day (MGD) for the year 1990.

Based on the results of the above projects and studies, the Environmental Protection Agency (EPA), Region II, prepared an Environmental Impact Statement (EIS) (5) in 1972. This EIS recommended that Nassau County study the feasibility of constructing a 5 MGD water reclamation-recharge, demonstration facility at its Cedar Creek Water Pollution Control Plant site. The EPA then authorized a $95,000 Federal Grant (R801478) for Nassau County to complete this recommended feasibility study. The County of Nassau entered into an agreement with the firm of Consoer, Townsend and Associates to conduct the feasibility study.

The result of this study, which lasted 12 months and was completed in August 1973, was a report (2) which listed the modifications and additions which must be made to convert part of the Cedar Creek Water Pollution Control Plant into a 5 MGD Water Reclamation Facility. This report was submitted to the EPA for approval, and in August 1974, the EPA approved this report and authorized the commencement of work on plans and specifications under the Construction Grants Program. This was a departure from the original plan of conducting the recommended demonstration project under the R & D program. By switching to the Construction

Grants Program, many side stream units and processes had to be deleted from the project as they were not fundable under this EPA program. The County, in October 1974, executed an agreement with Consoer, Townsend and Associates to develop plans and specifications for the Cedar Creek Water Reclamation-Recharge Facilities.

DESIGN & CONSTRUCTION

The plans and specifications were completed in early 1976. On March 24, 1976, a Public Hearing was held to discuss the results of the Environmental Assessment Statement (EAS) for this project. As there were no objections voiced at this hearing, the plans, specifications and EAS were submitted to EPA and New York State Department of Environmental Conservation (NYSDEC) for approval. On June 28, 1976, Nassau County was notified that it was awarded Federal Grant Number C-36-982.01 in the amount of $24,588,497. This grant award was for a combined Step 2 (Design), Step 3 (Construction) Grant. Costs under this Grant were to be shared as follows: EPA - 75% or $24,588,497, NYSDEC - 12 1/2% or $4,098,083 and Nassau County - 12 1/2% or $4,098,083 for a total project cost of $32,784,663. On November 16, 1976, the EPA and NYSDEC approved the plans and specifications for this project.

The design of the reclamation plant was based on producing an effluent which would meet the parameters shown in Table #1. In order to meet these proposed standards, the flow diagram shown in Figure #1 was developed. This design utilized the existing unused portions of the Cedar Creek Water Pollution Control Plant where possible. A description of the units shown in Figure #1 follows:

A. Reclamation Plant (1)

1. Chemically Aided Primary Treatment

The influent flow to the water reclamation plant is screened and degritted wastewater withdrawn under controlled conditions from the existing plant primary influent flow. The wastewater is conveyed to chemical treatment facilities. Contained in the chemical treatment facilities are a rapid mix tank for disposal of the lime, automatic lime slaking and feeding equipment, a slurry sludge tank and the required control and monitoring devices. The lime mixed effluent from the rapid mix tank is discharged by gravity to two flocculation chambers. In each of the chambers a horizontal shaft slow speed turbine mixer is installed for flocculation. The flocculated effluent then flows to existing primary tanks #5 and #6 which are used in the reclamation process.

The primary treatment system employs addition of lime followed by primary sedimentation to facilitate removal of phosphorus. Other benefits of lime addition include improved removal of BOD_5, suspended solids and heavy metals, thereby optimizing and protecting the biological nitrification system.

2. Two Stage Biological Treatment System

Utilizing all four passes of existing aerator No. 3 and final clarifiers #5, 7 and 8, the secondary treatment system has been designed to promote biological nitrogen removal in conjunction with oxidation of the remaining carbonaceous material. The design allows for the operation of the secondary system as a two stage growth system, with combined carbon oxidation-nitrification, intermediate claification, denitrification, post aeration-stabilization and final clarification. The settled wastewater from the primary tank flows by gravity to existing aeration tank #3. Passes 1 and 2 of the existing four pass aeration tank #3, which provide a detention time of 5.9 hours based on 5.5 mgd, will be utilized to introduce oxygen to the wastewater. An oxygen transfer rate of 11,200 scfm will be adequate to meet the increased oxygen demand of the combined carbon oxidation-nitrification system. From this combined carbon oxidation-nitrification portion of aerator #3, the mixed liquor enters existing 100 foot diameter final clarifier #5 which provides an overflow rate of 700 gallons per day per square foot. Activated sludge removed from this clarifier is returned to the carbon oxidation-nitrification tank, utilizing the existing return sludge well, pumps, meters and lines. The nitrified effluent from clarifier #5 passes to the denitrification tank (pass #3) which provides a detention time of two hours. Methanol is added to the tank influent flow at a rate of 3.54 lbs. per pound of nitrate-nitrogen and is applied as a supplemental organic carbon source in the denitrification process.

The denitrified liquor flows to a post aeration-stabilization tank (pass #4). The purpose of the post aeration-stabilization tank is to remove any supersaturated nitrogen gas, to avoid rising sludge problems in the final clarifier, to provide a mixing zone for the addition of alum and polymer for secondary phosphorus removal, and to provide an additional aeration period for the removal of excess methanol. The aerated liquor is conveyed to existing clarifier #7 for final clarification.

Operational flexibility is provided to allow conversion from a two stage to a three stage biological treatment system as a fail-safe mechanism to assure the production of a high quality effluent. Clarifier #5 is utilized between a high rate activated sludge unit and nitrification unit, clarifier #7 is utilized between the nitrification unit and the combined denitrification-post aeration unit, and clarifier #8 is utilized for final clarification.

3. Filtration and Carbon Adsorption

The design of the filtration and carbon adsorption system which will be housed in the soon to be constructed Building "R", is based on the use of multiple individual units, the size of which can be incorporated directly into a future full scale Nassau County recharge system.

The clarified effluent from the secondary system flows by gravity to the filter feed wet well where it is pumped under controlled conditions to automatically backwashed, mixed-media filters. Two gravity type filters are provided with two additional filters on standby. Each filter is 13' 4" wide and 38' 8" long, providing a surface area of 515 square feet and a filter rate of 3.75 gpm/sq. ft. based on a flow of 2.75 MGD. Backwash will be at a rate of from 15 to 20 gpm/ft^2. Surface washing equipment and air scour are provided. After passing through the filter media, the backwash water is pumped back to the Cedar Creek Water Pollution Control Plant influent well.

The carbon adsorption facilities consist of two contactor units in parallel, with two standby units provided. Each unit is 13' 4" wide and 38' 8" long, providing 515 square feet of surface area. Each unit will be filled with carbon to a depth of 8 feet. This will provide approximately 500,000 pounds of carbon and an empty bed detention time of 16 minutes per unit. The adsorption units are operated as downflow packed bed units. Backwash of the adsorbers will be similar to the backwash of the filters. When exhausted, the carbon will be regenerated in an onsite multi-hearth regeneration furnace.

4. Chlorination and Storage

A 30 minute chlorine contact chamber followed by a clearwell with a storage volume of 1.6 MG provides sufficient detention time for disinfection of the plant effluent. The clearwell serves as a pump suction chamber for service pumps to deliver treated water to the recharge site. The clearwell also provides the necessary equalization to permit continuous delivery of 5.0 MGD to the injection wells, despite fluctuations in plant output due to backwashing of filters and carbon adsorbers.

B. Transmission Main System

The proposed demonstration project involves the use of a 24 inch diameter concrete pipe transmission main to convey reclaimed water to the recharge site. A number of routes were investigated to determine the most cost-effective transmission system. The selected routing parallels the Wantagh State Parkway from the Cedar Creek treatment plant to the East Meadow recharge site. The length of transmission main required, using this route, is approximately 6.25 miles, or 33,000 linear feet.

C. Recharge Facilities

The proposed East Meadow recharge site is a triangular-shaped piece of County-owned land located in approximately the geographic center of the County. It includes approximately 60 acres of land which is occupied in part by the Nassau County Correctional Center and the structures and leaching basins of the Meadowbrook Sewage Treatment Plant.

Both shallow well and basin recharge studies will be conducted at the East Meadow site. The proposed program will recharge 4 MGD, with approximately 2.0 MGD recharged through wells. Five wells and ten basins will be used for the recharge studies.

The basins will be used to determine the management practices that are most effective for optimizing recharge; the evaluation of the clogging phenomena associated with the application of reclaimed wastewater; and the evaluation of the potential for the unsaturated zone to improve water quality. Of the five recharge wells to be installed at the East Meadow site, four will be in operation at any specified time, with one on standby. Each well recharges 0.5 MGD.

The East Meadow recharge site is surrounded by a monitoring network of 46 observation wells at 22 sites and manholes in basins #2 and #3. In addition, a sampling pump coupled with a composite sampler will be provided on the recharge site storage reservoir. The composite sampler will analyze reservoir water for dissolved oxygen, turbidity, temperature, pH, chlorine residual and specific conductance. Water from recharge basins #2 and #3 will be analyzed for pH, dissolved oxygen and sulfide.

Bids were advertised on November 26, 1976 as follows:

Contract #1002-3P-9	General Construction, Reclamation Plant
10	HVAC, Reclamation Plant
11	Plumbing, Reclamation Plant
12	Electrical, Reclamation Plant
14	General Construction, Recharge Facilities
15	HVAC, Recharge Site
16	Plumbing, Recharge Site
17	Electrical, Recharge Site

Since the construction of the reclamation and recharge facilities was expected to take 24 and 18 months respectively, it was decided to hold up on advertising Contract 1002-3P-13, General Construction of the Force Main as it was estimated that it would take 12 months to complete this phase of the project. Therefore, this contract was advertised for bid on May 25, 1977. Final bids for the above contracts were received as follows:

Contract	Contractor	Cost	Work Started
1002-3P-9	Nab Construction Corp.	$12,768,000	4/25/77
1002-3P-10A*	Dart Mechanical Corp.	892,480	7/18/77
1002-3P-11	Par Plumbing Co., Inc.	167,000	4/25/77
1002-3P-12	Cross Island Electric Corp.	797,850	4/25/77
1002-3P-13	Hallen-Schneider	4,979,927	10/3/77
1002-3P-14	Parks-Seidman, Inc.	2,297,660	4/25/77
1002-3P-15	Anron Air Systems, Inc.	69,000	5/23/77
1002-3P-16	C.F.Mentzinger's Son, Inc.	39,300	4/25/77
1002-3P-17	Cross Island Electric Corp.	143,780	4/25/77
	Total	$22,154,997**	

*Contract 10 rebid as contract 10A on April 20, 1977
**Grant C-36-982.01 was revised on November 14, 1977 to reflect the actual bid costs for this job. The new Grant amount is $19,346,804.

Construction of the reclamation plant, transmission main and recharge facilities has progressed to the point where only the estimated completion of April 25, 1979 for the reclamation plant will not be met. This is due to normal construction delays plus several delays in the design and acceptance of the instrumentation for the reclamation plant. Present projections call for the reclamation plant to be ready for start-up in early July 1979. The transmission main and the recharge facilities are complete except for landscaping work at the recharge site which cannot be completed until early spring 1979.

OPERATION

Since a New York State Department of Environmental Conservation SPDES (State Pollutant Discharge Elimination System) permit would be required in order to recharge the effluent from the reclamation plant, it was decided to make application for this permit in early 1978. Initial contact with EPA, NYSDEC and local and state Health Departments indicated that obtaining a SPDES permit would not be an easy task. The chemical and physical parameters to be listed in the permit were not the cause of concern, as New York State Drinking Water Standards, Part 72 or better were selected for the proposed reclamation plant effluent quality standards, and these standards were utilized in the selection and design of the various unit processes for the plant. The problem in finalizing the permit was caused by the fact that between 1972 and 1973, the period during which the preliminary design of the reclamation plant was developed, organic analysis had not progressed to the point where long lists of specific organic compounds were listed within drinking water standards or operating permits. During the time NCDPW was trying to finalize its SPDES permits, several Nassau and Suffolk County potable water wells were being closed due to organic contamination, and many organic compounds were classified as being carcenogens, teratogens, or mutagens. Finally, it was decided to perform an organic analysis (GC-MS) on the Cedar Creek Water Pollution Control Plant influent and effluent and to list those organics identified in the SPDES permit with the condition that all unidentified peaks which are exhibited in subsequent analysis shall be identified and reported. The list of organics persently specified in the SPDES permit are shown in Table #2.

Once the permit was formalized, it was time to develop a preliminary operating budget. Unfortunately, at this time, Proposition #13 was passing in California. The County of Nassau found itself in the position of adding a $2,000,000 annual operation and maintenance expenditure at a time when most Department budgets were being cut and layoff lists were being prepared. The result of this crisis was that the number of personnel to operate these facilities was reduced and certain line items for the first year of operation had to be deleted.

The operation and maintenance, including staff, associated with the project are anticipated to be $8,159,600 to $14,340,750 for a three to five year operating period.

Due to the highly technical nature of the reclamation-recharge project, Nassau County will enter into contracts with outside consultants for expertise in the area of tertiary plant operations, virological/microbiological work, organic analysis and systems analysis. An agreement has been executed with the USGS giving them full responsibility for operation of the recharge facilities. NCDPW personnel will provide maintenance services at the recharge site.

The County of Nassau filed for an operations and maintenance Grant under the federal "Environmental Research, Development and Demonstration Act of 1978" on July 17, 1978. This application was subsequently rejected by the EPA. The County is actively pursuing ways in which to involve units of the federal and state governments, under present legislation, to fund a portion of the operating costs for this project. At the time of this writing, the County has not received any word on the status of its requests from either the EPA or NYSDEC.

SCHEDULE FOR FIRST YEAR OF OPERATION

Since the recharge facilities are completed and it will be at least 9 months before the reclamation plant effluent will be available for recharge, the USGS personnel will have time to perform the following operations:

1. Install and calibrate the instrumentation in each of the observation wells and the manholes in basins #2 and #3.
2. Sample all of the observation wells in order to obtain background analysis for physical, chemical and organic contaminants present in the ground water table around the recharge site.
3. Prepare the surface of each of the recharge basins.

When construction of the reclamation plant is complete, there will be a three to six month period set aside for debugging equipment and training personnel in the operation of the reclamation plant. The firm of Consoer, Townsend and Associates is presently preparing the operations and maintenance manual for this project. The consultant personnel, with assistance from the handfull (8) of County personnel who have had previous experience with the operation of the Bay Park Water Reclamation Plant, will train those employees assigned to this project.

During the training period, the County will finalize several personal service agreements to provide for the following consultant services:

1. A virologist
2. A New York State certified laboratory to provide GC-MS analysis for organics, and
3. A computer maintenance firm to maintain the reclamation plant computer.

Recharge should begin in January 1980. Operation of all facilities will be for a minimum period of three years and a maximum period of five years. As the operation of the reclamation plant proceeds during the three to five year test period, various side stream unit processes may be investigated as follows:

1. Ozone or chlorine dioxide disinfection.
2. Use of fluidized bed reactors for carbonaceous removal, nitrification and denitrification.

During recharge, the USGS will be conducting the following investigations:

1. Comparing shallow well recharge to basin recharge.
2. Comparison of basins with and without surface vegetation.
3. Comparison of various vegetation covers.
4. Comparison of various basin surface soils.
5. Comparison of various basin surface maintenance practices.
6. Comparison of various basin application rates and cycles.

The USGS will also monitor the observation wells to determine the path the recharge water is taking and to examine any changes which take place during its travel.

After the above operating period has been completed, the biological portion of the Cedar Creek Plant will be reconverted back to a secondary treatment, step aeration, facility. Assuming the operation proves successful, additions can be made to the permanent filter and adsorption building, while the conventional biological portion of the plant will have to be converted to provide chemical addition and nitrogen removal in a new, permanent facility. The transmission main has been designed to carry 20 MGD and therefore can be utilized along with the recharge facilities.

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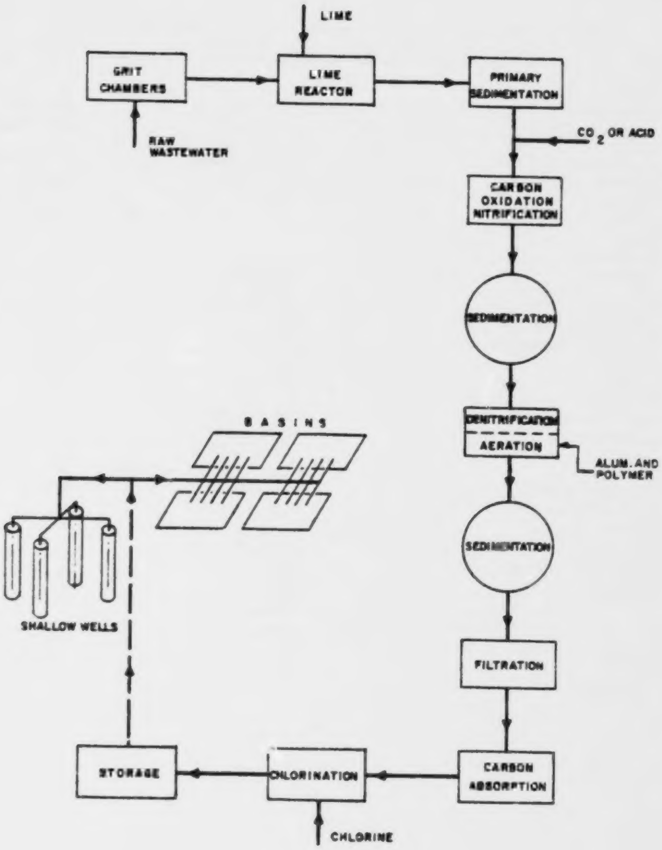

FIGURE 1

SCHEMATIC DIAGRAM OF
WATER RECLAMATION-RECHARGE FACILITIES

Table No. 1
Water Quality Standards For Cedar Creek Reclamation-Recharge Project

Constituent or Characteristic	Desired Limit mg/1
ABS	0.5 mg/1
Aluminum	0.1
Arsenic	0.05
Barium	1.0
BOD_5	2.0
Boron	1.0
Cadmium	0.01
Calcium	<Sat. Con
CCE	0.2
Chloride	250
Chlorine Res. (Free)	1.0
Chromium (hexavalent)	0.05
Copper	0.2
Cyanide	0.1
Fluoride	1.5
Iron & Manganese Combined	<0.3
Lead	0.05
Mercury	0.005
Nitrogen, Total	3.0
O_2Consumed	2.0
Phenols	0.001
Phosphorus	0.1
Selenium	0.01
Silver	0.05
Sodium	50%of Cations or 20 mg/1
Sulfate	250
TOC	3.0
Uranyl Ion	5.0
Zinc	0.3

Constituent or Characteristic	Desired Limit mg/1
Microbiological	
Coliform Org.	4/100 ml. max. 1/100 ml. avg.
Pesticides	
Aldrin	0.017
Chlordane	0.003
DDT	0.042
Dieldrin	0.017
Endrin	0.001
Heptachlor	0.018
Hep. Epoxide	0.018
Herbicides	0.1
Methoxychlor	0.035
Org. PO_4 + Carbamates	0.1
Toxaphene	0.005
Physical	
Color	15 units
TON	3 units
TDS	500
Turbidity	0.5 J.T.U.
Entrained Air	None
SS	1.0
pH	6.5-8.5 units

TABLE #2

Effluent Parameter Organic	Discharge Limitations Daily Max.	Monitoring Reqmts. Measurement Frequency	 Sample Type
Chloroform	100 ug/l	weekly	grab
Trichloroethylene	10 "	"	"
Tetrachloroethylene	50[1] "	"	"
Ethylbenzene	50[1] "	"	"
1, 1 Dichloroethane	50[1] "	"	"
1, 1, 1 Trichloroethane	50[1] "	"	"
Carbon Tetrachloride	5 "	"	"
Methylene Chloride	50[1] "	"	"
Dichlorodifluoromethane	50[1] "	"	"
Toluene	50 "	"	"
Benzene	N.D.[2]	"	"
Paradichlorobenzene	4.7 "	"	"
Orthodichlorobenzene	4.7 "	"	"

[1] Total aggregate concentration of these constituents shall not exceed 100 ug/l.

[2] Not detectable by tests or analytical determinations referenced in Section 703.4 NYCRR.

Note: All unidentified peaks which are exhibited in analyzing for the above constituents shall be identified and reported. Analysis shall be performed by utilizing the purgeable, headspace or solvent extraction methods appropriate for the constituents in question and performed in a State Health Department approved laboratory.

DIRECT RECHARGE FOR EL PASO, TEXAS

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This paper discusses the development, planning, and testing work done to date on a water reuse project in El Paso, Texas involving aquifer recharge by direct injection of reclaimed sewage.

AREA DESCRIPTION

El Paso is located in westernmost Texas along the International border with Mexico which is formed by the Rio Grande (Figure 1). Desert scenery, sunbelt weather and a multi-cultural character provide El Paso with an attractive environment. These attributes have spurred rapid growth in recent years (3% per annum since 1970), and as of 1978 the city population was about 400,000. The metropolitan region, including Ciudad Juarez, contains about 1,000,000 residents.

WATER DEMANDS

In 1977 the El Paso water utility produced and distributed 92,800 acre-feet of water (1.145×10^8 m^3) with a per capita consumption of about 210 gallons (795 l) per day. About 36% of the demand occurs in winter months while 64% occurs in April-September. During dry summer periods (especially June) daily demands can reach 400 gcpd (1515 l/person day). Water demands are forecasted to be as shown on Figure 2. From 1980 to 2050, 14.5 million acre-feet (17.9×10^9 m^3) will be required with only 2.5 million acre-feet (3.08×10^9 m^3) available from steady state supplies, i.e., surface water and natural ground water recharge.

EXISTING WATER SOURCES

Currently the City of El Paso obtains approximately 10% of the supply from the Rio Grande, 25% from the ground water sources in the Cantuillo area, and 65% from the Hueco Bolson ground water source. It is evident that the Bolson supply is the dominant source for the City at present. This is due to its low cost, good quality and the ease with which it can be obtained and distributed, even during the peak summer season. Studies made by the U.S. Geological Survey indicate that the Bolson has approximately 10 million acre-feet (12.33×10^9 m^3) of fresh water in storage in the Texas portion of the aquifer. A significant supply of saline water adjoins and underlies the fresh reserves. Annual Bolson recharge is about 5% of current withdrawals, including the inflow from New Mexico.

It is estimated that 9 million acre-feet (11.1×10^9 m^3) of Bolson water are available to the City, plus the entire annual recharge amount. If pumping over the next 60 years averages 150,000 acre-feet (1.85×10^8 m^3) per annum; then the aquifer will be 97% exhausted in the year 2040. This calculation is crude and based on several simplifications; however, it illustrates the basic point that the low-cost water supply available to the City from the Hueco Bolson is finite; and that within the foreseeable future there will be a significant need to obtain new water supplies to supplement the Hueco Bolson.

FUTURE WATER SOURCES

Several alternatives are available to augment the water supplies in the future although all are costly and not all are steady state supplies but a continuation of the current practice of mining. Some of the water resources adjacent to El Paso are not available as water sources to the City.

Substantial reserves of ground water occur in bolson deposits in New Mexico, adjacent to the El Paso area. This source would provide a low-cost supply for the City, but is not available due to restrictions in New Mexico state law. The large flow of the Rio Grande is a relatively low-cost, but erratic, source of supply for the City. However, the water is controlled by the local irrigation district and, historically, attempts to increase municipal use of this supply have not been successful in the courts.

Alternatives which are available and their forecasted contribution to future supplies are shown on Figure 2. These include conservation, small amounts of surface water rights, desalinization, wastewater recycling, importation from other bolsons and continued mining of the Hueco Bolson.

Conservation, that is avoid increased demand by education programs, ordinances, rate increases and rate designs, will provide substantial savings in water-use without radical changes in the local economy or life-style. For planning purposes, a decline in water use of 5-10% is anticipated.

One of the options, slight expansion of river use under existing contracts provides a small increment in available water. Desalinization provides a modest additional supply at high costs and is estimated at 2 million acre-feet (2.47 x 10^9 m^3). Recharge of the Hueco Bolson with highly treated waste water consumes large quantities of chemicals and energy but does provide a steady state supply. Recharge is forecasted to supply about 30% of the future demand.

Importation from another West Texas Bolson some 150 miles to the east of El Paso is expensive. Implementation of this alternative will require difficult land acquisition problems and large front-end capital investments. The committment to energy-intensive pumping will exceed that required to reclaim wastewater.

The option of exchanging a treated wastewater for river water or potable water used by industry is limited due to court decision regarding river water and the lack of large water using industries.

Costs for several of these alternatives are shown on Table 1.

DEVELOPMENT OF PROJECT

Sewage Treatment Requirement

The requirement for additional sewage treatment facilities in the Northeast area of El Paso prompted a P.L. 92-500 Section 201 study of the Northeast service area. Existing treatment facilities consist of three (3) oxidation pond cells and an evaporation pond constructed in the early 1960's. The total pond surface area is about 322 acres

(130 ha) and was designed for no discharge.

Since the current flow rate grossly exceeds the evaporation capabilities of the system, an overflow evaporation/percolation pond has resulted on property not owned by the City. The resulting percolation of oxidation pond effluent is also contaminating the Hueco Bolson.

Alternatives Considered

The Facilities Plan and concurrent "piggyback" E.I.S. prepared for the service area studied several alternatives. These alternatives included discharge to the Rio Grande, agricultural reuse, industrial reuse, and ground water recharge. Most alternatives involved multiple reuses since only a few of the reuse opportunities could use all of the wastewater. All alternatives used a 10 mgd (38,000 m^3/day) design flow.

In the evaluation of alternatives for cost effectiveness, a value was placed on water recharged or conserved based upon the replacement value of the water. Because of this, water replaced above ground was assigned a value of \$1.19/1000 gallons (\$0.31/m^3) and water replaced in the aquifer was considered to be worth \$1.19 less lifting costs or \$1.04/1000 gallons (\$0.27/m^3).

The cost effective alternative, selected on the basis of economics and public input, was the alternative involving industrial reuse and direct recharge of the Hueco Bolson. This alternative is shown on Figure 3.

TREATMENT PROCESS DEVELOPMENT OBJECTIVES

Objectives

The recharge alternatives considered that the reclaimed wastewater would meet all drinking water standards as well as other non-drinking water requirements prior to recharge on a continuous basis. Several sources were investigated to determine what parameters should govern the quality of the recharged water.

The primary regulatory requirements are the National Interim Primary Drinking Water Regulations, including the proposed organic chemical requirements, and the Texas Department of Health Drinking Water Standards. Additionally the regulatory requirements for the Orange County Project were also considered. Table 2 presents the requirements of the various regulatory agencies, existing well water quality, raw sewage quality, and the proposed effluent quality.

The proposed treatment plant would be designed to meet the criteria listed. It is realized that drinking water standards are established considering the raw water supply is relatively protected, and would not have the pollutant load of wastewater stream. For this reason the treatment process must have a high factor of safety for removal of those pollutants which are difficult to identify, particularly toxic materials, trace organics, and viruses.

Effluent parameters affecting recharge wells are anticipated to be turbidity and entrained air. Chemical incompatabilities are not expected to be a problem based upon a U.S.G.S. analysis of Hueco

Bolson chemistry and the proposed effluent. Turbidities of less than 0.5 NTU are set as a requirement.

The treatment process selection for the recharge alternative must be one which gives the highest degree of reliability and removal of all potential contaminants through multiple units. Ideally each unit should be chosen so that it adds to the reliability of the overall process by providing redundancy for another process unit. Effluent quality reliability is not only the most important criteria from a health standpoint but from a physical and monetary standpoint as well since only effluent meeting quality criteria may be discharged. Thus, water not meeting quality after treatment will require the expense of retreatment.

Influent Characteristics

The influent characteristics listed on Table 3 indicates a moderately weak sewage which is primarily domestic in origin. Current contributions are about 85 gpcd (322 l/person day) and flows are around 5.5 mgd (20,900 m^3/day).

Process Selection

Figure 4 illustrates the several treatment trains studied to obtain the optimum treatment technique. Process units involving ponds were not evaluated due to the high evaporation rates in El Paso and the resulting TDS increases.

Primary Treatment. All treatment flow schemes investigated utilized primary treatment and equalization of the primary effluent. The use of primary clarifiers lowers the amount of inert materials in the following process units and removes settleable solids which simplifies the design and operation of the equalization basins. In all cases the primary clarifiers followed screening and degritting.

Primary clarifiers with integral thickeners were chosen to produce a higher density sludge without the odor and other operating problems associated with primary sludge thickeners. Sludge densities of 6% should be obtainable with the integral thickener. Anaerobic digestion was recommended as the sludge stabilization process since it is a net energy producing process and the sludge process used extensively in El Paso.

The anaerobic digesters selected were single stage high-rate complete mix with dewatering on sand beds. Dryed sludge will be composted as is done at other El Paso treatment plants and sold as a soil conditioner.

Equalization. The process proposed, where numerous chemical feed rates are involved and high product quality control is of utmost importance, would benefit greatly from flow equalization.

Equalization was located after primary treatment since the primary treatment process is relatively unaffected by flow equalization, given properly designed clarifiers, and storage of primary effluent is relatively simple. The existing oxidation ponds on the treatment plant site hold approximately 300 MG (1.14×10^6 m^3) and are currently the only method of treatment. This volume provides a volume sufficient not only for equalization but for a 30 day plant shut down as well.

Carbonaceous Removal. A great portion of the BOD and the related COD of the incoming sewage should be removed in a biological system. This is suggested since very high removals are required and there are certain BOD or COD causing constituents which are easily biodegradable and can be removed through physical or chemical means only with great difficulty.

Since the El Paso waste water temperatures vary between 16°C and 31°C, removals of 96% of the soluable BOD_5 are possible with sludge retention times (SRT) of 3 to 4.5 days. The SRT's required for this removal will also be sufficient for nitrification.

Several methods of biological treatment for carbonaceous removal were examined, including bio discs, conventional suspended growth, combined carbonaceous and nitrogen removal (BARDENPHO), and a suspended growth biological system with powdered activated carbon (PACT). It can be seen from Figure 4 that the approach to optimum carbonaceous removal involves several other unit processes.

It was felt necessary to insure that the carbonaceous removal system, which would use some type of biological system in all cases, was extremely reliable. To provide this reliability, a roughing carbon contact unit was used in front of all "pure" biological systems to isolate the bio-system from periodic toxic discharges which may occur in a sewage collection system. This carbon contactor would utilize spent carbon from the final GAC process.

Where the PACT (powdered activated carbon activated sludge) system was considered, the bio system reliability and protection from toxicity was considered to be provided by the PAC in the mixed liquor. This carbon, about 7,200 mg/l (volatile), co-mingled with the 4,800 mg/l of biomass has provided reliability in many pilot studies.

Nitrogen Removal. The nitrogen removal method selected must remove nitrogen which is in the nitrite or nitrate form since the sludge retention times (SRT'S) necessary for high carbonaceous removals and the temperature of the wastewater will encourage the growth of nitrifying bacteria. When this occurs, such processes as ammonia stripping, ion exchange, and breakpoint chlorination would not be effective and were therefore not considered.

A two stage biological nitrogen removal process consists of a first stage incorporating carbonaceous removal and nitrification in one activated sludge system with a SRT of 15 days based upon a minimum growth type of biological system ie. bio-disc with similar design parameters. Further, the carbonaceous removal and nitrification could be separated into two separate systems either fixed or suspended growth.

The second step of the two stage process must be operated in an anoxic (D.O. less than 0.5 mg/l) mode and must be fed with a pure carbon source such as methanol so that the anoxic denitrifying bacteria have a food source to allow them to convert the nitrates formed in the first stage to nitrogen gas. The second stage system can be a suspended growth type system with a covered reactor tank followed by an uncovered nitrogen stripping section. The second step could also be a fluidized bed reactor. In each case design criteria involves methanol doses of around 3 mg/l carbon to each mg/l of nitrate removed.

There is a potential problem with methanol in that trace organics may be included in the methanol source thus adding to the amount of organics to be removed or too much methanol addition may cause methanol bleed through and a resulting high effluent COD.

A combined biological process such as the "BARDENPHO" process marketed in the U.S. by Envirotech has the advantage of accomplishing carbonaceous and nitrogen removal in one process step. This process utilizes the carbonaceous material in the incoming sewage as a carbon source for denitrification. In this process the oxygen released,as nitrates are converted to nitrogen gas, is available for use by the incoming waste. This lowers the overall oxygen requirements when compared with the conventional two stage treatment approach. The long detention times involved this process (SRT = 21 days) result in performance similar to extended aeration with the production of a relatively low amount of very stable sludge. Cost calculations of the BARDENPHO system considered that the sludge generated from the system required only dewatering prior to composting.

The two stage biological physical process has been recently developed by the DuPont and Zimpro companies which combines the biological system and the use of powdered activated carbon (PAC). The system utilizes high concentrations of PAC in the activated sludge reactors thus allowing the biodegradable and adsorbable materials to be removed in the same process.

In general, the system evaluated was based upon a proposal by Zimpro, Inc. which incorporates a two stage system with wet air regeneration of the powdered carbon. The first stage consists of a reactor and clarifier very similar to a standard activated sludge system, the difference being that the reactor mixed liquor suspended solids (MLSS) concentrations (MLVSS plus volatile carbon) are held around 12,000 mg/l. The mixed liquor will include another 20 to 30% of suspended ash material resulting from dead bio-mass and ash associated with the PAC. A ratio of PAC to bio-mass of 1.5 to 1 in the 4.5 hour basin retention time gives an SRT of 13.5 days, a conservative value for nitrification. Where it is necessary to increase the SRT the MLSS can be raised to 20,000 mg/l. In this reactor the bio-mass can utilize the organic materials adsorbed on the carbon particles as food thus partially regenerating the carbon. The presence of carbon in the mixed liquor also provides a sink for toxic materials entering the basin and therefore provides considerable process reliability.

The settleability and stability of the PACT system sludge allows extremely high floor loading on the clarifiers. Values of 200 lb/sqft/day (977 kg/m^2/day) are possible with the PACT sludge, although it is necessary to use polymer in the clarifiers to aid in flocculation of some of the fine carbon particles. As a result of the sludge stability, substantial denitrification can be accomplished in the clarification units of the first stage by regulation of the sludge withdrawal rate and the sludge blanket. Total nitrogen removal rates of 30% are normally obtained in the first stage.

Waste sludge and powdered carbon regeneration are processed in a wet air oxidation unit which oxidizes the sludge to ash and regenerates the PAC. The wet air oxidation unit is very similar to the units used for the wet air oxidation of sludges except that higher temperatures (400°F, 236°C) and higher pressures (800 psia, 56.2 kgf/cm^2) are used. The wet air oxidation unit processes 6% suspended solids material and reduces the suspended solids to 3.4% by oxidizing the biological solids and materials adsorbed onto the PAC. This 3.4% suspended solids stream is regenerated PAC and is returned to the head of the first stage reactor. The inert sludge ash is blown down from the reactor and dewatered to 50% S.S. suitable for hauling to land fill. Since all regeneration is carried out in a liquid filled pressured reactor there are no air pollution concerns.

The second stage of the PACT system utilizes a 1.5 hour anoxic detention and a 0.9 hour aerobic detention time. PAC is also used in the second stage with MLSS concentrations of 12,000 mg/l (excluding ash). A PAC to bio-mass ratio of 2.8 is maintained so that the denitrifying bio-mass is 3150 mg/l. All virgin PAC is added in this stage with the waste sludge and carbon fed to the first stage to provide a counter current carbon contacting system. The second stage SRT is 7 days which allows utilization of the incoming BOD as a carbon source.

Methanol is fed to the second stage to be used as a carbon source by the denitrifying bacteria. Because nitrogen is removed in the first stage and some carbon is available from both the incoming BOD and from materials adsorbed on the carbon, the methanol to nitrate ratio in the range of 1.4 to 1 has been observed in pilot studies.(2)

The expected effluent quality on a soluable basis from the PACT system is:

COD, mg/l	<10
Total Kjeldahl Nitrogen, mg/l	<1
Ammonia Nitrogen (NH_3-N), mg/l	<1
Phosphorus mg/l	<5
Total Nitrogen mg/l	<1
TOC mg/l	<5

The PACT system was selected for it offers the benefit of a total of 20 days SRT, a two stage operation, reliability, and potential savings when the cost of downstream carbon processes are considered.

Lime Treatment. The use of a high lime process was considered mandatory due to the wide band heavy metal removals, high viral kills, and phosphorous removal performance of the process. A pH level of 11.1 was selected based upon viral removal and metal removal performance.

Lime dosages to reach specified pH values can be estimated based upon pH/alkalinity relationships. From this the lime dosage can be seen to be increasing as the water alkalinity at the point of treatment increases. In a wastewater treatment plant this becomes important where nitrogen is removed through biological means since the nitrification process destroys alkalinity and denitrification adds alkalinity. Nitrification destroys alkalinity at the rate of 7.4 mg of alkalinity per mg of NH_3-N oxidized. Approximately 2.95 of alkalinity as $CaCO_3$

is produced per mg of nitrogen reduced. Lime dosages would vary as shown on Table 4.

The lime treatment process would be located after nitrification if lime usage were the only criteria. There are disadvantages to lime treatment after nitrification since it is unknown whether or not a denitrification step following lime treatment would have sufficient incoming biology to provide a stable denitrification operation. The effect of the lime treatment upon the methanol dose is unknown since the lime could eliminate potential carbon sources present in the nitrification effluent. Another potential problem is encountered where a powdered carbon denitrification system follows the lime treatment. Here the lime carry over could fill the carbon pores with an inert material and require premature replacement of the powdered carbon.

Lime treatment was located after denitrification even though it is not the lowest cost location. This location eliminates the potential disadvantages listed above since biology and methanol considerations would not be of concern and filtration after the lime process would contain lime carryover in the lime/filtration system. It is also desirable from a virus kill standpoint to lime treat the water at the lowest practicable turbidity level. Application after denitrification would be slightly better since TSS levels are lower. Lower turbidities would also be expected to give lower interferences with the lime-heavy metal reactions.

Lime treatment prior to nitrification is the highest cost lime treatment location by a significant amount. In this case the lime treatment would be prior to biological treatment to gain the benefit of lower BOD and COD loading on the biological system. The benefits of lower loading do not offset the greatly increased lime costs (10¢ per 1000 gallons). Alternatives using lime in the primary clarifier have not been examined in detail since the sludge disposal technique used in El Paso, composting for sale, could not be used and the effects of increased turbidity upon virus and heavy metal reactions would be undesirable.

Recarbonation. A two stage recarbonation system is utilized in the process to provide calcium carbonate equilibrium.

Turbidity Removal. Sand filtration was located after recarbonation and before disinfection. The recarbonated effluent is readily filterable and a low turbidity at the point of disinfection is necessary.

Disinfection. Although bactericidal considerations are important, viral and cyst removal requires special consideration in this type of a project. The influent concentrations of virus and cysts are expected to be quite high compared with normal water sources and the measurement techniques are relatively inexact, the organisms are small, and some viral organisms live for several months. Current technology uses various chlorine compounds, ozone, and ultraviolet radiation for disinfection.

All options considered high lime for gross reductions. Ozone was selected as the final disinfecting process due to its advantages over chlorine in disinfection performance and in halogen formation properties. Ozone also provides the potential of improving the performance of the following GAC process by breaking down organics and assisting bio-activity on the carbon.

Removal of Residual Organic Compounds. The reduction of the taste and odor compounds, pesticides, herbicides, synthetic organics, trihalomethane precursors, and trihalomethanes is required through existing or proposed drinking water criteria.(6) (7)

The literature reports four general treatment unit processes currently available for removal of the organic compounds these are: precipitation/filtration, oxidation, aeration, and adsorption. Of these methods granular activated carbon has been chosen as the best "broad spectrum" unit process for controlling organic contaminate concentration. Another combined process, Biologically Activated Carbon (BAC), that of oxidation and adsorption using ozone and activated carbon has recently been developed.

Of the four processes available, precipitation/filtration will account for a 60% reduction in suspended organic carbon concentration. Oxidation with ozone or chlorine is not economical at a reasonable removal level and by-products formed with the chlorine reaction are self defeating. Aeration is only effective at tremendously high air to water ratios which make it economical only in conjunction with ammonia stripping. Adsorption on activated carbon is the only broad based process for removing dissolved organic materials from water.(7)

Since the residual organics seem to be the major health question where recycling is concerned, several of the unit processes selected for El Paso are to provide organics removal.

In order of application, the two-stage PACT system is proposed to do the bulk of the organic removal. Following this a high lime coagulation process will provide some treatment of the undissolved organics. Filtration after lime treatment will further reduce the suspended organics. Ozonation is planned after filtration and prior to a final GAC filter thus providing a BAC system for final polishing.

Mineral Removal. The total dissolved solids (TDS) in the plant influent are approximately 300 mg/l higher than that water delivered into the potable water system. The TDS buildup must be considered in the process design since the water produced from the recharged areas of Hueco Bolson could potentially exceed the allowable TDS value (1000 mg/l). Additionally, the TDS values of the non-recharged Hueco Bolson water increases as the reservoir is depleted thus the two increasing TDS trends aggrevate the problem.

The forecasted TDS and the mineral buildup in the aquifer due to this project is shown on Table 5. Currently, the mineral buildup is not of concern although future injection projects on the Hueco Bolson of a greater magnitude may require a demineralization process.

Pilot Testing

The PACT portion of the process was piloted for about four months. The PACT effluent was lime treated, filtered, ozonated, and GAC filtered on a batch basis to obtain unit process information and to determine final effluent qualities.

PACT System. The PACT pilot plant was a small (200 ml/min) rack mounted unit. As a result of the size, some upsets occurred due to plugged tubing and poor performance of the small clarifiers. The pilot schematic is shown on Figure 5.

Table 6 shows the preliminary data obtained during the last month of piloting. COD values are within the process requirements. TOC and ammonia removals are about as expected. Nitrogen removals are only 76% leaving an effluent concentration of 7.59 mg/l NO_3 as N. This level was high because methanol dosage was limited to about 8 mg/l to avoid the possibility of overdosing and the resulting effluent TOC, COD and BOD increase. These nitrogen levels were accomplished at a methanol to nitrate-N feed ratio of 0.5 which is much better than 3.0 used in conventional biological denitrification systems. The overall methanol feed rate is held to 8 mg/l± due to denitrification in the first stage clarifier. The effluent values were lowered to zero by increasing the methanol feed rate to a 1.4 ratio; however, methanol overdosing problems resulted due to the small pilot plant and the lack of adequate real time influent nitrate measurement capability.

The performance of the PACT system as a THM removal system is high averaging 96%. THM precursor removal is not known, however, the few samples chlorinated to 0.5 mg/l free chlorine residual indicate influent values from 100 to 1000 ug/l and PACT effluent values from 20 to 300 ug/l after 24 hours.

Trace organics testing of the PACT influent and effluent was done during the pilot period. The results of this testing are shown on Table 7 along with similar analysis run on raw sewage and on drinking water from the Hueco Bolson. Samples were analyzed by GC-MS techniques for the 125 organic chemicals included on the list of "Priority Pollutants" and on the list of "Chemical Indicators of Industrial Contamination." Results of this testing indicate methylene chloride concentrations of 72 ppb in the drinking water and 38 ppb in the PACT effluent. Laboratory contamination is suspected here as it is very unlikely the Hueco Bolson is contaminated with methylene chloride. In a different set of tests, 95 ppb of bis (2-ethylhexyl) phthalate were found. This chemical is used in the production of Tygon tubing which is used extensively for pilot plant sampling lines.

One sample of the PACT effluent used in the GC-MS analysis had a TOC of 250 mg/l due to a methanol overdose, but none of the 125 organics were found. Trace organics originating from methanol do not therefore seem to be a problem.

Overall Process Performance. The data obtained by batch treating the PACT pilot plant effluent is compiled on Table 8 to indicate the water qualities through the treatment plant. The data presented are subject to some variability since not all testing was done at the same time thus influent fluctuations affected the measured parameters.

The pilot work indicated the proposed process could meet drinking water standards operating as designed. It was not determined, however, how often the final GAC filter would need to be regenerated but data indicated trihalomethane precursors running as high as 300 ug/l would govern the bed life. It is planned that the bed life will be determined in the full scale operation since piloting the entire plant long enough to determine the effect of ozone on the carbon is not practicable.

The process provided the unexpected benefit of lowering sodium and TDS levels across the PACT system. This is probably due to the biological nitrogen removal system and the alkalinity change.

An effort was made to evaluate the carcinogenicity of the product water since the removal of carcinogenic materials is a major consideration in a treatment process such as the one proposed. Accordingly, various water samples were tested with a modified Ames procedure(5). The tests involved using the histidene-dependent strains of Salmonella, TA 98, TA 100, TA 1535, TA 1537 and TA 1538 with and without rat liver microsomes to detect mutagenic and/or carcinogenic compounds in unconcentrated water samples.

The test results are shown on Table 9. Initial tests indicated PACT effluent was mutagenic and that El Paso drinking water (Nevins reservoir) was not mutagenic with or without 2% PACT effluent added to it. Further testing was done to determine if the treatment processes down stream of the PACT units would remove the mutagenic properties. Here, the product water was ozonated effluent, without GAC treatment, chlorinated to 0.5 mg/l free residual. The testing indicated exceedingly small mutagenic properties with 1:1 and 9:1 mixtures of Nevins reservoir water and product water. Undiluted product water did not display mutagenic properties.

The limited data suggests that the product water used in the tests was at least as good as Nevins reservoir water and that the combination of lime, filtration and ozonation does remove the mutagenic property.

RECHARGE SYSTEM

Recharging of the Hueco Bolson may be accomplished through percolation basins or through the use of injection wells. Injection wells were selected due to low surface area requirements, higher recoveries and the potential for energy recovery. Figure 6 shows the location of production wells within the immediate vicinity of El Paso.

Artificial recharge of the northernmost well fields appear to offer the greatest potential benefit to the City of El Paso when compared to the other well fields in the aquifer. The City of El Paso owns most of the water in this locality, as shown on Figure 6 and would receive the most benefit from a artificial recharge program. Figure 6 also illustrates the forecasted 1903 to 1990 Hueco Bolson water level decline.(3) As shown on the figure, the recharge wells are located such that it is likely all of the recharged water will be recovered by the city since gradients are generally toward the city's production wells.

Injection rates are expected to be one half to two thirds of the capacity of production wells in the area. Existing wells range in capacity from 1000 to 1500 gpm (5472 to 8208 m^3/day) thus injection rates from 600 to 850 gpm (3283 to 4636 m^3/day) are expected. At these injection rates, 10 injection wells are necessary to handle the 10 mgd (38000 m^3/day) plant capacity. The wells will be constructed in a manner similar to the existing production wells. A pump will be installed in each well so that periodic backflushing and redevelopment is possible.

Liquid levels in the injection wells during operating will most probably be around 300 feet (91.5 m) below the ground surface if no provisions are made to increase the injection well head losses. Injection tests in the Hueco Bolson have shown that provisions must be made to control the head loss, preventing air entrainment and the resulting loss of injectivity.

A potential for energy recovery exists due to the 300 ft. (91.5 m) head loss incurred by 10 mgd (38000 m^3/day). Assuming an 80% recovery about 320 KW could be recovered by down hole turbines which would effectively solve the air entrainment problem. The turbine could be reversible for use as a backflushing device. Injection tests will more accurately determine the injection well performance so that a detailed evaluation of the turbine technique can be made.

COSTS

The capital costs for the project are $29,000,000 using 1981 construction costs (STP CCI 316) and operating costs are estimated to be $2,200,000 per year in 1983 dollars.

CONCLUSION

Recharge was chosen for El Paso because a) it solves existing wastewater problems; b) it adds to the steady state drinking water supply; c) it is a prototype for larger-scale recycling which would provide more than one-fourth of El Paso's water needs over the next 70 years; d) the water supply benefits of recycling are judged by the public to warrant increased dollar costs, resource use and environmental impacts; e) alternative wastewater recycling projects do not address municipal water supply concerns; and f) alternative water supply projects, such as importation, are even more expensive and will result in significant resource use and environmental impact.

The treatment process selected adequately met the process requirements with some benefits, i.e. sodium removal and TDS removal, which were unexpected.

ACKNOWLEDGEMENT

The author is grateful to the many employees of El Paso Water Utilities and Zimpro, Inc. involved in this project. Many people were involved and all participated with enthusiasm.

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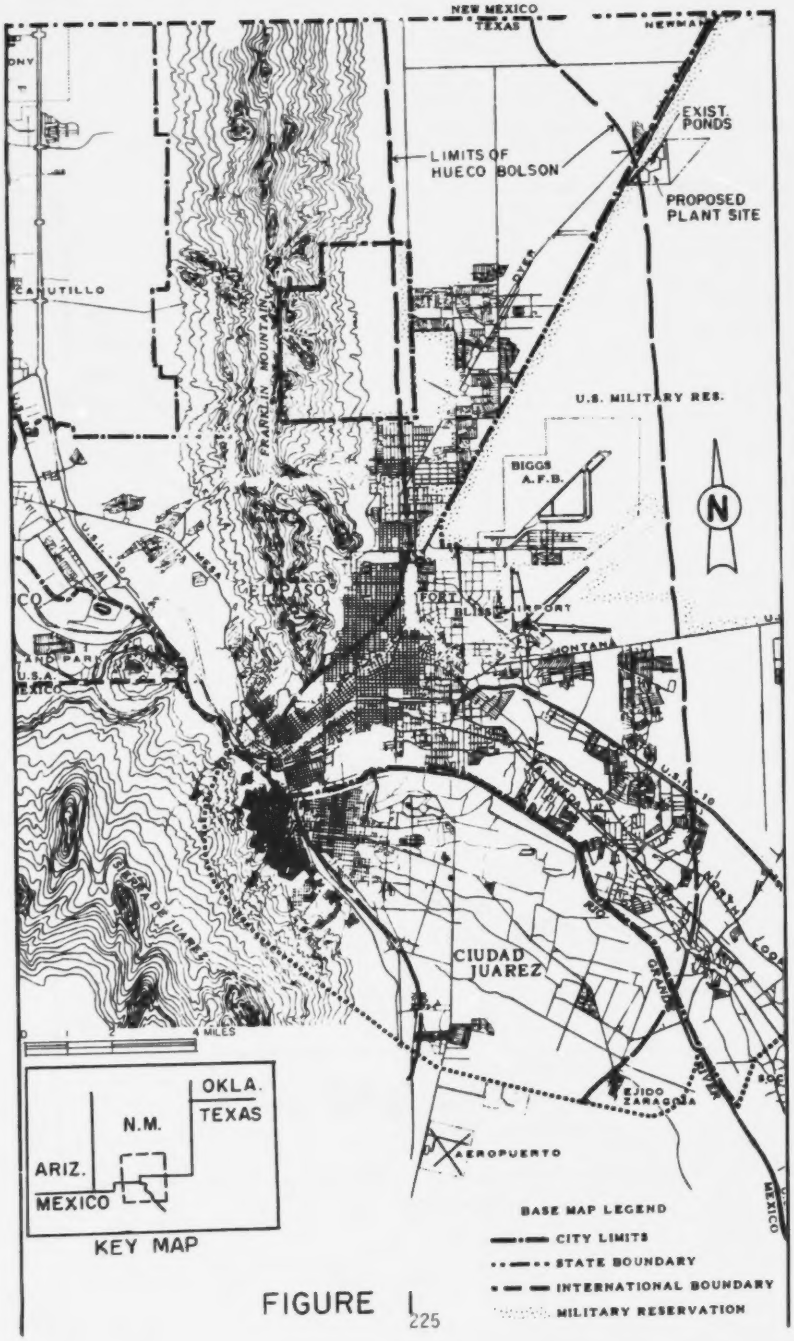
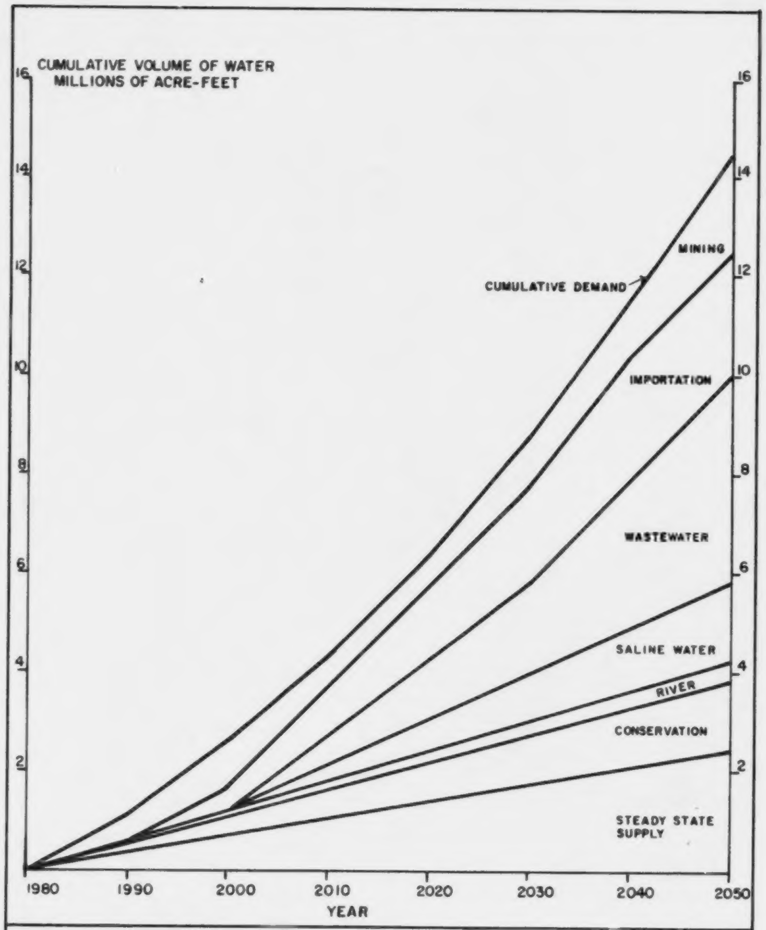
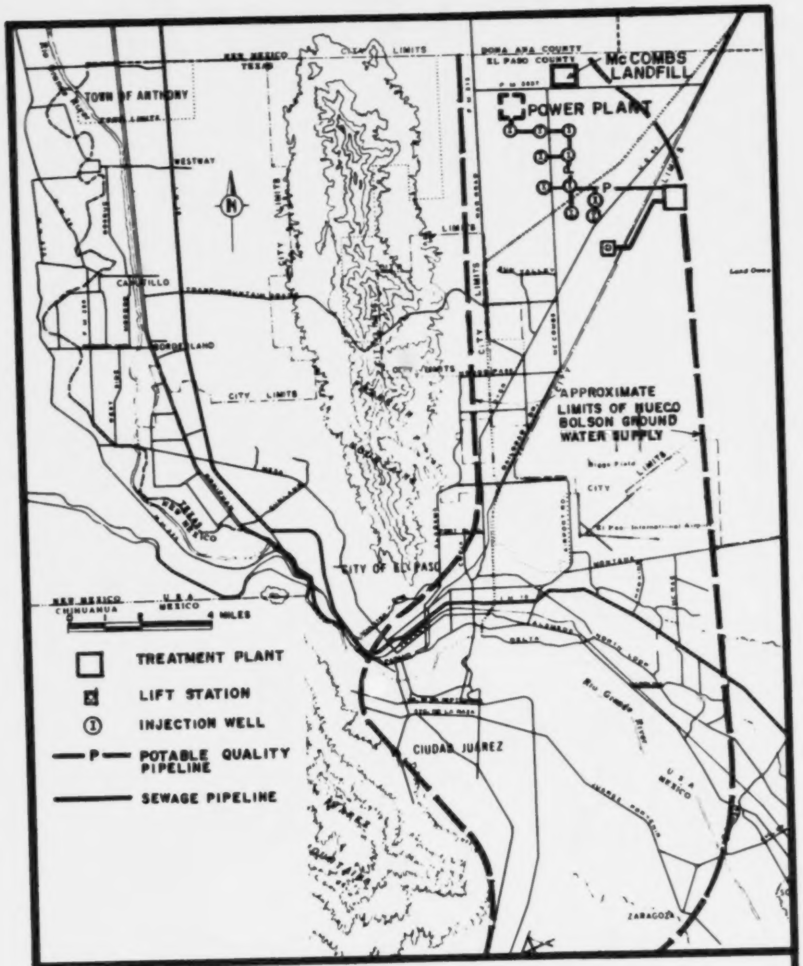

NEW MEXICO
TEXAS
EXIST. PONDS
LIMITS OF HUECO BOLSON
PROPOSED PLANT SITE
CANUTILLO
FRANKLIN MOUNTAIN
U.S. MILITARY RES.
BIGGS A.F.B.
N
MESA
EL PASO
FORT BLISS
AIRPORT
MONTANA
U.S.A.
MEXICO
SIERRA DE JUAREZ
CIUDAD JUAREZ
NORTH LOOP
RIO GRANDE
EJIDO ZARAGOZA
AEROPUERTO
0 1 2 4 MILES
OKLA.
TEXAS
N.M.
ARIZ.
MEXICO
KEY MAP
BASE MAP LEGEND
CITY LIMITS
STATE BOUNDARY
INTERNATIONAL BOUNDARY
MILITARY RESERVATION

FIGURE 1



CUMULATIVE DEMAND FOR AND SUPPLY OF WATER
RESOURCES IN THE CITY OF EL PASO, 1980-2050
(FROM E.I.S.)

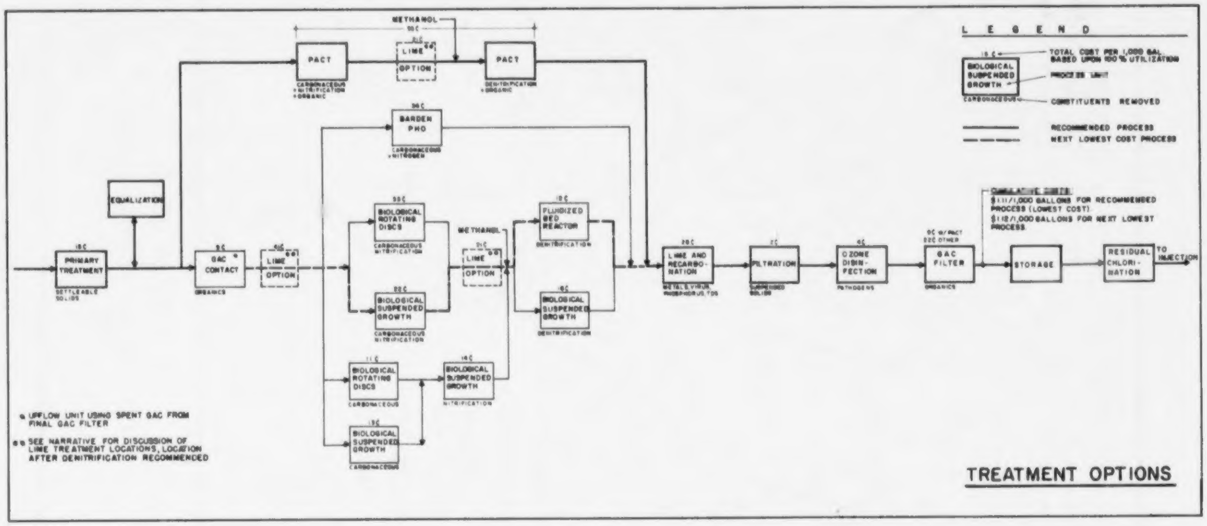
FIGURE 2



ALTERNATIVE 6

RECHARGE AND INDUSTRIAL REUSE
ONE WATER TYPE

FIGURE 3



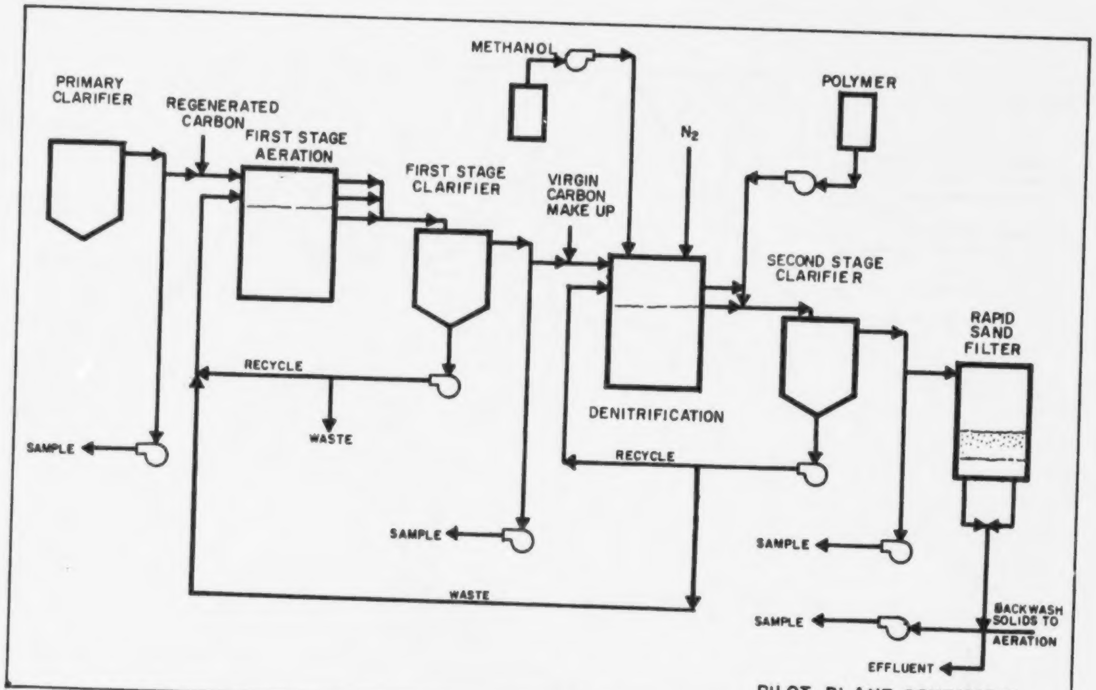
CUMULATIVE COSTS:
$111/1,000 GALLONS FOR RECOMMENDED PROCESS (LOWEST COST)
$112/1,000 GALLONS FOR NEXT LOWEST PROCESS

* UPFLOW UNIT USING SPENT GAC FROM FINAL GAC FILTER

** SEE NARRATIVE FOR DISCUSSION OF LIME TREATMENT LOCATIONS, LOCATION AFTER DENITRIFICATION RECOMMENDED

TREATMENT OPTIONS

FIGURE 4



PILOT PLANT SCHEMATIC

FIGURE 5

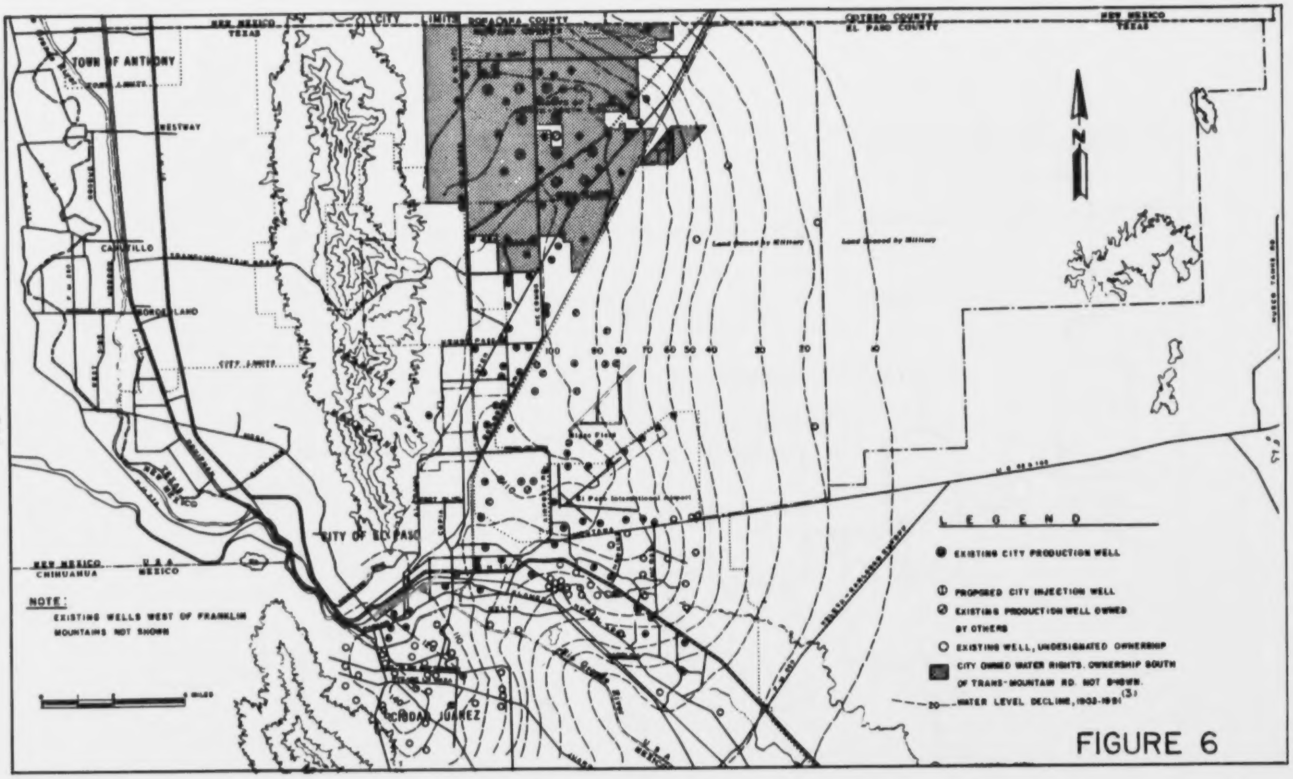
TOWN OF ANTHONY
CANUTILLO
CITY OF EL PASO
CIUDAD JUAREZ
NEW MEXICO
TEXAS
DONA ANA COUNTY
OTERO COUNTY
EL PASO COUNTY
CITY LIMITS
WESTWAY
El Paso International Airport
Land Owned by Military
NEW MEXICO
CHIHUAHUA
U.S.A.
MEXICO
NOTE:
EXISTING WELLS WEST OF FRANKLIN MOUNTAINS NOT SHOWN
MILES
LEGEND
● EXISTING CITY PRODUCTION WELL
PROPOSED CITY INJECTION WELL
EXISTING PRODUCTION WELL OWNED BY OTHERS
○ EXISTING WELL, UNDESIGNATED OWNERSHIP
CITY OWNED WATER RIGHTS. OWNERSHIP SOUTH OF TRANS-MOUNTAIN RD. NOT SHOWN.
20 WATER LEVEL DECLINE, 1903-1991(3)
10
20
30
40
50
60
70
80
90
100
110
N

FIGURE 6

TABLE I

VALUE OF ADDITIONAL WATER RESOURCES IN EL PASO, TEXAS
COST PER 1,000 GALLONS (1983)

I. **RIVER WATER** (Limited To Small Parcels Or 0.18 MGD Per Year)

First Cost	$ 0.021
Annual Cost	0.374
Treatment	0.327
	$ 0.722 / 1,000 Gal.

II. **BRACKISH WATER DESALTING**

Lifting	$ 0.20
Treatment	2.22
	$ 2.42 / 1,000 Gal.

III. **RECHARGED WATER**

Treatment And Injection	$ 1.56
Credit For Sewage Treatment	-(0.65)
Lifting	0.15
	$ 1.06 / 1,000 Gal.

IV. **IMPORTATION FROM OTHER WEST TEXAS SOURCES**

Lifting	$ 0.15
Transportation	1.04
	$ 1.19 / 1,000 Gal.

TABLE 2

WATER QUALITY

Parameter	Units	EPA Drinking Water Standard	Texas Dept. of Health	Orange Co. California	Hueco Bolson Wells	Northeast Sewage	Proposed Effluent Quality
Alk	mg/l				129	250	150
NH_3-N	mg/l			1.0		25	< 0.1
B	mg/l			0.5		< 1.0	< 0.8
Ca	mg/l				45	35	50
Cl	mg/l		300*	120	64.7	122	140
COD	mg/l			30		400	< 10
E Coli	MPN/100 ml.	1	1	0			0
EC	umho/cm			900	510	1200	1000
F	mg/l	1.4 to 2.4	1.4 to 1.8	0.8	1.0	0.9	0.9
Mg	mg/l				10.6	7.9	3.0
pH	-		7.0*	6.5 to 8.0	8.1	7.1	7.5 to 8.0
PO_4-P	mg/l				< 0.5	20	0.1
Na + K as Na	mg/l			110	96	192	145
SO_4	mg/l		300*	125	53.7	125	125
SiO_2	mg/l				38	38	38
TH	mg/l			220	102	120	140
Total-N	mg/l			10		36	2
Nitrates as N	mg/l	10	10		< 2.1	0	1.5
TOC	mg/l						< 2
Turb.	NTU	1	1	1.0	0.14	97	< 0.5
T.S.S.	mg/l					150	< 1.0
Cyanide	mg/l			0.02			0.02
As	mg/l	0.05	0.05	0.05		.008	0.05
Ba	mg/l	1.0	1.0	1.0		0.46	0.1
Cd	mg/l	0.010	0.010	0.010	< 0.01	< 0.01	< 0.01
Cr	mg/l	0.05	0.05	0.05	< 0.05	0.01	0.01
Cu	mg/l		1.0*	1.0	< 0.1	< 0.05	< 0.05
Fe	mg/l		0.3*	0.3	< 0.1	< 0.31	0.05
Pb	mg/l	0.05	0.05	0.05	0.05	< 0.05	< 0.05
Mn	mg/l		0.05*	0.05	0.01	< 0.05	< 0.05
Hg	mg/l	0.002	0.002	0.005		0.002	0.0014
Se	mg/l	0.01	0.01	0.01		< 0.0035	0.01
Ag	mg/l	0.05	0.05	0.05		< 0.01	< 0.01
Zn	mg/l		5.0*		0.1	< 0.1	< 0.1
Al	mg/l					.28	< 0.15
Color	Color Units		15*			52	< 10
Foaming Agents (ABS)	mg/l		0.5*	0.5		3.5	0.2
Corrosivity			non-corrosive*				non-corrosive
H_2S	mg/l		0.05*			1.0	0.01
Odor	Threshold Odor No.		3*				1
TDS	mg/l		1000*		391	770	680
D.O.	mg/l						1.0
Phenol				0.001	0.001	0.004	0.001
Entrained Air							None
Chlorine Resid.				Free Resid.			0.25 Free
Virus							0
Endrin	mg/l	0.0002	0.0002				< 0.0002
Lindane	mg/l	0.004	0.004				< 0.004
Methoxychlor	mg/l	0.1	0.1				< 0.1
Toxaphene	mg/l	0.005	0.005				< 0.005
Chlorophenoxys:							
2,4-D	mg/l	0.1	0.1				< 0.1
2,4,5-TP Silvex	mg/l	0.01	0.01				< 0.01
Total Trihalomethanes	mg/l	0.10**					< 0.10
Volatile halogenated Compounds***	ug/l	0.5**					< 0.5
Combined radium 226 and 228	pCi/l	5	5				< 5
Gross alpha particle Activity (excluding radon and uranium)	pCi/l	15	15				< 15
Average annual Dose Equivalent for beta particle and photon radio-activity from man-made radionuclides	mrem/yr	4	4				< 4

* Secondary Standard
** Proposed Standard
***Each Compound

TABLE 3

INFLUENT CHARACTERISTICS

		Raw Sampling Program 11/77 to 1/78			**Pilot Plant Settled Influent Characteristics** 10/78 to 1/79		
		Mean	Stand. Deviation s	Number of points n	Mean	s	n
BOD_5	mg/l	165,2	53.0	46	146	26.2	24
sol. BOD_5	mg/l	124.7	47.3	46			
COD	mg/l	397.5	137.9	74	319	115	25
sol. COD	mg/l	189	59.4	74			
sol. TOC					34.7	10.9	51
PO_4-P	mg/l	18.4	7.9	73	15.11	4.10	22
TSS	mg/l	136.6	71.9	73	5.03	24.3	25
TKN-N	mg/l	34.7	3.1	61	31.1	9.1	26
NH_3-N	mg/l	24.6	2.51	63	23.9	4.7	26
H_2S	mg/l	.78	.48	55			
TDS	mg/l	677.4	76.2	73			
pH		7.0	.18	78			
Alk. mg/l $CaCO_3$		229.5	50.9	73	239.6	20.0	23
B	mg/l				.3	0	3
Cl	mg/l	144.3	16.9	60	166.5	62.9	2
F	mg/l	.93	.09	66			
Mg	mg/l	5.74	1.64	66	11.12	1.90	3
Ca	mg/l				50.9	23.8	3
Na	mg/l	177.2	9.8	66	140	17	3
SO_4	mg/l	95.3	24.7	66			
TH mg/l as $CaCO_3$		102.9	4.2	31			
As	mg/l				.005	.003	3
Ba	mg/l	0.32	.88	34	0.16	.03	3
Cd	mg/l	0.10	.08	43	<.01		3
Cr	mg/l	0.05	.002	58	0.036	.006	3
Cu	mg/l	0.11	.2	57	0.037	.013	3
Fe	mg/l	0.20	.08	41	0.2	0.14	3
Pb	mg/l	0.07	.04	58	0.03	0.002	3
Mn	mg/l	0.04	.01	41	0.019	.008	3
Hg	mg/l	0.0014	0.0014	58	<0.001		3
Se	mg/l				0.00325	.0003	2
Ag	mg/l	0.026	0.019	44	<.01	0	3
Zn	mg/l	0.116	0.119	58	.04	.025	3

TABLE 4

LIME DOSES

LOCATION OF TREATMENT	ALKALINITY mg/L as $CaCO_3$	LIME DOSE mg/L (100 % CaO)	COST, CENTS PER 1,000 Gal.
Before Nitrification	250	408	41
After Nitrification	72	122	21
After Denitrification	142	243	28

TABLE 6

PACT PILOT PLANT PERFORMANCE — JAN. 1979

PARAMETER	INFLUENT	EFFLUENT	% REMOVAL
BOD	153.4	4.75	96.6
COD	273.6	10.9	96.0
TOC (Soluble)	31.4	2.86	90.9
TKN-N	30.5	0.59	98.0
NH_3N	23.3	0.153	99.3
NO_3N	0.12	7.59	–
TN	30.5	8.22	73.0
TSS	42.3	3.11	92.6
PO_4-P	14.9	13.1	12.1
Alkalinity As $CaCO_3$	228.0	117.6	48.4
THM ug/L	2-4	0.03-0.13	96.0
THMFP ug/L (24 Hours)	100-1,000	20 - 300	70-80

Values In mg/L Except As Noted

TABLE 5

CHANGES IN HUECO BOLSON WATER QUALITY

Parameter	Existing Water Quality	Water Quality Average in 1998-2003 When 12.1% Of Produced Water Has An Injection Origin	Water Quality at Individual Wells Directly Down Gradient From and Near the Injection Well
Total dissolved solids mg/l	400	435	605
Sodium mg/l	96	106	152
Chlorides mg/l	65	69	87
Sulfate mg/l	54	60	90

All Estimates Consider 10% of Injected Water Injected in a Previous Cycle (From E.I.S.)

TABLE 7

TRACE ORGANICS TESTING

SAMPLE POINT		POTABLE WATER	RAW INFLUENT	PACT INFLUENT		PACT 1st STAGE EFFLUENT		PACT 2nd STAGE EFFLUENT	
DATE OF ANALYSIS		11/2/78	5/78	11/2/78	11/17/78	11/2/78	11/17/78	11/2/78	11/17/78
TOC	mg/l			51.3	31.9	7.48	7.14	250.0	4.84
VOLATILE ORGANIC COMPOUNDS	ug/l								
Benzene		0.9	1	0.2		2.8		0.5	
1,1,1 Trichloroethane		2.6		0.4		6.1		0.6	
Chloroform		1.2	2	0.2	0.9	1.5	UTD	1.1	12
Methylene Chloride		72	<1	8.4		23		38	
Trichlorofluoromethane		4.2		0.2		8.6		0.8	
Tetrachloroethylene				2.9		0.8			
Toluene				0.5		4.0		0.1	
Trichloroethylene		1.1		0.1		2.5			
Ethylbenzene						1.0			
Bromoform		0.5							
1,1- Dichloroethylene			<1						
trans 1,2- Dichloroethylene			1						
1,2- Dichloroethane			<1						
1,1,2,2 - Tetrachloroethene			<1						
1,1,2,2 - Tetrachloroethane			<1						
OTHER ORGANICS	ug/l								
Napthalene		1.7		0.8					
Pentachlorophenol		11		29		17		4.6	
Phenol		1.8		3.7					
Acenaphtylene		0.5							
1,4 - Dichlorobenzene		2.4							
2,4 - Dichlorophenol		0.9							
Bis (2- Ethylhexyl) Phthalate			2	1.0	125.0	23	17.0		95
Di-n- Butyl Phthalate					4.0		10.0		3
Diethyl Phthalate					6.0		0.3		0.5
Butyl Benzyl Phthalate			3		3.0		2.0		
Chlordane			<1						

Only Those Organics Detected In The Search Of 124 Are Listed

Detection Limits = <0.2 ug/L On 5/78 Samples: = <0.1 ug/L On 11/2/78 Samples; = <0.5 ug/L On Volatiles,
<1.0 ug/L On Acid And Base Neutrals And Pesticides On 11/17/78.

UTD = Unable To Determine By Protocol Method.

TABLE 8

OVERALL PILOT TESTING RESULTS

	RAW	PACT INF.	PACT 1	PACT 2	HIGH LIME	RECARB 1	RECARB 2	0.4 m m FILT.	0.4 Resid. OZONE	GAC FILT.	PROPOSED EFFLUENT
COD mg/l		260		5.6	10.4		<8.7	13.0	<8.7	<8.7	<10
TOC mg/l		35	5.0	2.2	2.2		-1.81	-1.81	1.81	0.78	<2.0
NH$_3$ mg/l		23	<0.1	<0.1							<0.5
NO$_3$(TKN) mg/l		(37)		.3(1.5)							1.5(2.0)
Coliforms - Total MPN/100 ml				38,000	1		15	2	0	0	0
Alkalinity - T (Alkalinity - P) mg/l	235	235		140	172(124)		172(0)	158(0)	150(0)		150
Total Phosphorus mg/l as P				7.01	1.0					<1.0	0.1
pH				7.36	11.1	9.3	7.45	7.8	7.8	7.8	7.5
Turbidity, NTU	97			2.6	9.4		2.5	0.35	0.20	0.16	0.5
TDS mg/l	769			622			667	645	633	649	680
T.H. mg/l as CaCO$_3$	120			124			144	140	142		140
Ca mg/l	35			38			51	50	52		50
Cl mg/l	122			122			124	124	124	140	140
Mg mg/l	7.9			7.0			4.0	3.6	2.9		3.0
Na mg/l	192			152	145		153	149	145		145
SO$_4$ mg/l	125						125	125	125		125
Cyanide mg/l										<0.015	0.02
As mg/l		0.006	0.006	0.0015	0.0015					.005	< .05
Ba mg/l		0.15	0.28	0.13	0.14					0.02	0.1
Cd mg/l		<0.01	<0.01	<0.01	<0.01					<0.003	<0.01
Cr mg/l		<0.03	<0.03	0.04	0.03					.012	<0.01
Cu mg/l		0.004	0.08	0.022	0.012					.010	<0.05
Fe mg/l				0.036	0.029					.018	0.05
Pb mg/l		0.032		0.028	0.026					.026	<0.05
Mn mg/l		0.026		0.010	0.010					0.010	<0.05
Hg mg/l		<0.001	<0.001	<0.001	<0.001					<.001	0.0014
Se mg/l		.0035		0.0031							<0.01
Ag mg/l		<0.01	<0.01	< .01	< .01					<.01	<0.01
Zn mg/l		0.058		0.012	<0.010					.003	<0.1
Color APHA units	52									<5	<10
Σ THM ug/l		1.2		< .05							<100
Σ THMFP ug/l 24 Hr.	100-1000			20 - 300							<100

TABLE 9

AMES TESTING RESULTS

EFFECT OF WATER SAMPLES ON REVERSION OF SALMONELLA IN AMES TEST

WATER SAMPLE	S 9(2)	Salmonella Strain(1) TA 100	TA 98	TA 1535	TA 1538	TA 1538	Displays Mutagenic Properties
TESTS RUN		12/13/78					
CONTROL	-	229 ± 55	9 ± 13	33 ± 6	16 ± 3	22 ± 6	
	+	386 ± 41	52 ± 8	17 ± 5	22 ± 4	27 ± 5	
PACT EFFLUENT	-	703 ± 99	38 ± 40	50 ± 12	45 ± 9	55 ± 22	
	(t;p)	(12.5;<0.001)	(2.4;0.05-0.1)	(3.8;0.01-0.05)	(8.1;<0.001)	(4.3;0.01-0.02)	Yes
	+	668 ± 119	165 ± 34	33 ± 10	66 ± 10	54 ± 8	
	(t;p)	(6.7;<0.001)	(7.9;<0.001)	(4.3;0.01-0.02)	(12.2;<0.001)	(8.6;<0.001)	Yes
NEVINS RESERVOIR WATER	-	218 ± 52	4 ± 10	29 ± 6	19 ± 3	22 ± 6	
	(t;p)	(NS)(3)	(NS)	(NS)	(NS)	(NS)	No
	+	430 ± 90	48 ± 10	17 ± 4	26 ± 5	28 ± 8	
	(t;p)	(NS)	(NS)	(NS)	(NS)	(NS)	No
98% NEVINS RESERVOIR WATER	-	230 ± 54	11 ± 17	28 ± 7	16 ± 4	17 ± 4	
	(t;p)	(NS)	(NS)	(NS)	(NS)	(NS)	No
2% PACT EFFLUENT	+	397 ± 54	47 ± 11	17 ± 4	17 ± 6	17 ± 4	
	(t;p)	(NS)	(NS)	(NS)	(NS)	(NS)	No
TESTS RUN		1/11/79					
CONTROL	-	270 ± 34	34 ± 7	14 ± 5	11 ± 8	17 ± 5	
	+	294 ± 59	35 ± 8	26 ± 5	20 ± 5	14 ± 3	
50% PRODUCT WATER(4) AND	-	496 ± 99	78 ± 10	30 ± 7	10 ± 3	25 ± 6	Exceedingly
	(t;p)	(6.8;0.001-0.002)	(11;<0.001)	(5.8;0.01 - 0.002)	(NS)	(3.2;0.02-0.05)	Small
50% NEVINS RESERVOIR WATER	+	296 ± 60	32 ± 3	10 ± 3	19 ± 4	23 ± 7	Exceedingly
	(t;p)	(NS)(4)	(NS)	(NS)	(2.8;0.02-0.05	(NS)	Small
10% PRODUCT WATER AND	-	276 ± 43	37 ± 8	21 ± 6	25 ± 7	19 ± 6	Exceedingly
	(t;p)	(NS)	(NS)	(NS)	(5.4;0.002-0.01	(NS)	Small
90% NEVINS RESERVOIR WATER	+	400 ± 79	50 ± 7	9 ± 3	21 ± 7	17 ± 3	Exceedingly
	(t;p)	(3.4;0.01-0.02)	(4.4;0.01-0.002)	(NS)	(NS)	(NS)	Small
100% PRODUCT WATER	-	272 ± 25	39 ± 6	22 ± 3	12 ± 6	20 ± 3	
	(t;p)	(NS)	(NS)	(NS)	(NS)	(NS)	No
	+	298 ± 53	31 ± 5	7 ± 3	16 ± 5	12 ± 2	
	(t;p)	(NS)	(NS)	(NS)	(NS)	(NS)	No

(1) Values are mean number of colonies ± SD: 10 plates for each valve.

(2) - = without rat liver microsomes, + = with rat liver microsomes.

(3) NS = Not significant in student "t" test

(4) Product water is PACT effluent which had been batch lime treated, recarbonated, filtered, ozonated and chlorinated to 0.5 mg/l free residual. Water had a TOC of 3.84 mg/l and a turbidity of 0.22 NTU and had not been GAC filtered.

Tests run by Gulf South Research Institute, New Orleans, Louisiana.

PURECYCLE CORPORATION
A DOMESTIC WASTEWATER RECYCLING SYSTEM

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The conservation of water resources has become increasingly important in the past decade and will increase in importance in future years due to population growth, increase consumption and pollution of existing supplies. Natural and covert reuse of water has been known and practiced for many years. Treated and untreated wastewater from domestic and industrial sources has been discharged to rivers and streams, this same water then treated and distributed for potable use. Septic tank/leach field discharge percolates to sub-surface aquifiers which are used for sources of potable water. The degree of treatment in these cases is dependent upon nature and there is little if any control or mandatory treatment.

The combining of conservation of water, control and monitoring of the treatment of water, at an affordable capital and operating expenses, was the objective of PureCycle Corporation of Boulder, Colorado. By confining and integrating five subassemblies, wastewater is treated and purified for reuse as potable water. The System is controlled and monitored by a microprocessor which is tied into a common telephone line for communication with a service center. (See Figure 1.)

The spent water from a domestic residence is delivered to the System usually using a four inch line with a slope of 1/4 inch per foot. The spent water is first treated via anerobic digestion and solids settling. Following this aerobic digestion is employed using a rotating biological contractor (RBC). The primary function of the aerobic digestion is conversion of organic matter to stable forms such as carbon dioxide and water. The anerobic process is designed to stabilize compounds with nitrates and sulfates. The complete digestion of these organic and inorganic compounds is not necessary because following the process is organic adsorption and demineralization. Because there are these subsystems following the digestion, temporary failure of the digestor does not imply that water quality will be impaired during these times.

Separation of solids from the effluent of the digestor is accomplished by an ultrafilter. The ultrafiltration membranes have a pore size of 50 angstroms. This pore size prohibits the passage of bacteria, viruses, other biological contaminants down to a molecular weight of 50,000. A backflush system is employed to periodically clean the filter. Should the ultrafilter rupture and allow passage of solids, a nephelometer would detect them at a level of .02 NTU. The microprocessor has been preprogrammed to shut the system down at a turbidity of a .33 NTU and auto-dial a service center to notify a failure.

Organic compounds not destroyed in the anerobic/aerobic digestor, or not retained by the ultrafilter, are adsorbed by the activated carbon in the adsorption system. Although the ability of activated carbon to perform over a broad range of organic carbons is difficult to predict, activated carbon adsorption has been used successfully in this application many times over. The United States Environmental Protection Agency has proposed that some municipal water utilities use activated carbon to reduce the level of trihalomethanes in water supplies. The monitoring of the adsorption system is done by an on-line ultraviolet light absorbance monitor capable of detecting organic carbons at less than 100 ppb.

Inorganic material and polar organic matter are extracted using ion exchange resins. The hydrogen form and hydroxide form of the ion exchange resins are similar to resins used in commercial applications to provide deionized water. To determine when the resin capacity has been reached and regeneration is necessary, a conductivity cell monitors the effluent of this subsystem. A separate subsystem, the chemical plant, is designed to provide, by electrolysis of aqueous sodium chloride, sufficient amounts of acid and base. This acid and base is used to wash the appropriate resins for regeneration. Again the microprocessor controls this function as needed.

Ultraviolet (U.V.) sterilization is the final treatment of the water in the purification system. Disinfection of waters via U.V. radiation is dependent upon several factors:

1. Energy and exposure
2. Transmission of the liquid
3. Liquid flow rate

U.V. radiation must hit the micro-organism to destroy it and each organism must absorb a specific amount of energy to be destroyed. Table I gives the absolute amount of U.V. energy necessary to kill many of the common types of micro-organisms. The germicidal spectrum of the ultraviolet wavelength is from 2,000 to 3,000 angstrons, with the peak at 2,537 angstroms. The intensity of the ultraviolet radiation is expressed in microwatts per square centimeters at a given distance. The total U.V. energy emitted from all sides of the U.V. lamp is expressed in watts. The total exposure of the liquid is expressed as micro-watt seconds per square centimeter, or "Ultrads," which is a product of energy, time and area. The same number of Ultrads can be accomplished with a short exposure at a high intensity of U.V. or a long exposure at a low intensity of U.V.

The amount of energy available to an organism from a given ultraviolet source is dependent upon the U.V. transmission of the liquid. The transmission of the liquid is dependent upon the quantity and types of dissolved and suspended matter in the liquid. The highly polished water with average turbidity of 0.15 NTU produced by the System has an absorption coefficient of less than 0.008. The System's U.V. sterilizer produces an excess of 300,000 Ultrads for sterilization. After sterilization, the processed water is stored in a 1,500 gallon tank and on demand pumped to the house for all normal uses, such as drinking, cooking, bathing, laundry, etc.

The water quality data on the processes water is exhibited in Table II, and as can be seen the quality is equal to or better than most municipal supplies.

The System has been designed to resolve the problem of building homes where water, either quality or quantity, is a problem and/or on-site treatment of wastewater is a problem.

TABLE I
ULTRA VIOLET ENERGIES AT 2537 ANGSTROMS NECESSARY TO INHIBIT COLONY FORMATION IN 90% OF THE ORGANISMS AND FOR COMPLETE DESTRUCTION

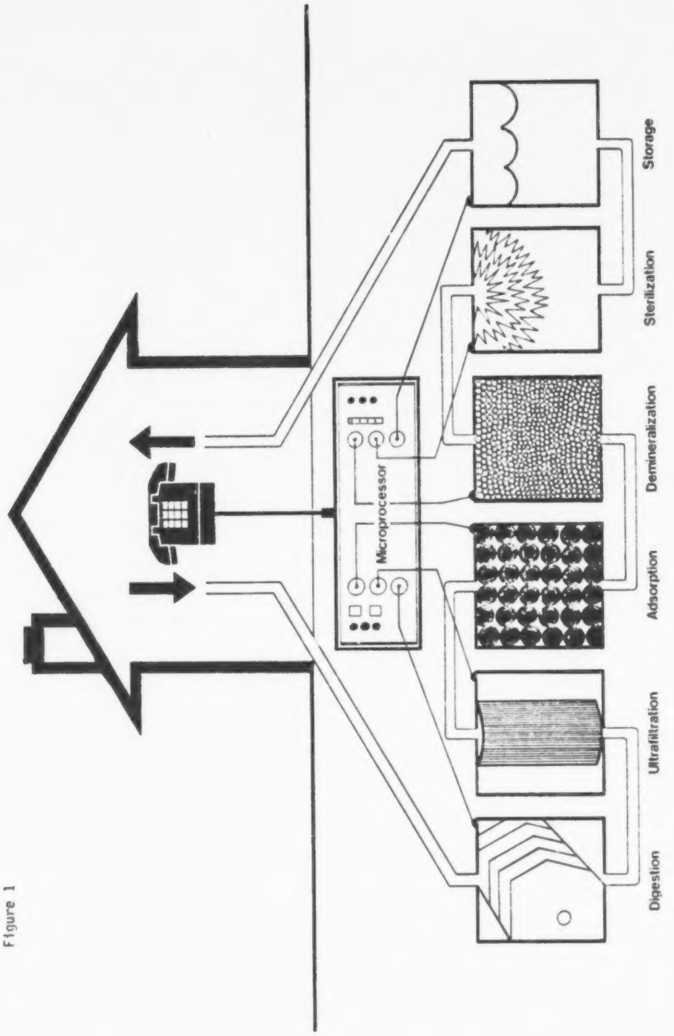
ORGANISM	ENERGY 90%	(MW-SEC/CM^2) 100%
Bacillus	4520	8700
S. Enteritidis	4000	7600
B. Megatherium sp. (veg.)	1300	2500
B. Megatherium sp. (spores)	2730	5200
B. paratyphosus	3200	6100
Bacillus subtilis	5800	11000
Bacillus subtilis spores	11600	22000
Corynebacterium diphtheriae	3370	6500
Eberthella typosa	2140	4100
Escherichlia coli	3000	7040
Micrococcus candidus	6050	12300
Micrococcus sphaeroides	10000	15400
Neisseria catarrhalis	4400	8500
Phytomonas tumefaciens	4400	8500
Proteus vulgaris	3000	7480
Pseudomonas aeruginosa	5500	10500
Pseudomonas fluorescens	3500	7040
S. typhimurium	8000	15200
Sarcina lutea	19700	26400
Serratia marcenscens	2420	6160
Dysentery bacilli	2200	4200
Shigella paradysenteriae	1680	3400
Spirillum rubrum	4400	6160
Staphylococcus albus	1840	5720
Staphylococcus aureus	2600	6600
Streptococcus hemolyticus (alpha type)	2160	5500
Streptococcus lactis	6150	8800
Streptococcus viridans	2000	3800
Salmonella typhosa - typhoid fever		4100
Salmonella paratyphi - enteric fever		6100
Shigella dysenteriae - dysentery		4200
Shigella flexneri - dysentery		3400
Vibrio Comma - cholera		6500
Leptospira Spp. - infectious jaundice		6000
Poliovirus - poliomyelitis		6000
Virus of Infectious hepatitis		8000
Bacteriophage - E. Coli		6600
Tobacco mosaic		440000
Influenza	3400	6600
Protozoa - paramecium		200000
Nematode eggs	40000	80000
Algae		22000

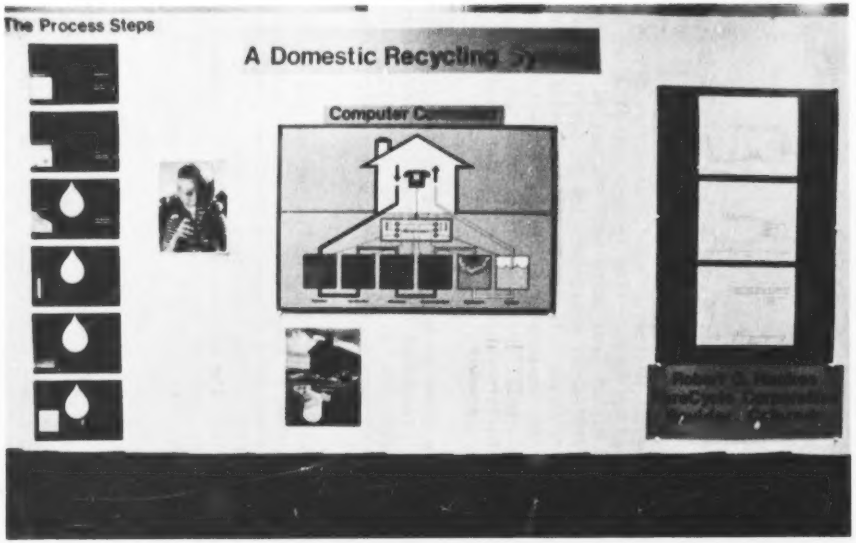
	ENERGY	(MW-SEC/CM^2)
ORGANISM	90%	100%
Yeast		
Saccharomyces ellipsoidues	6000	13200
Saccharomyces sp.	8000	17600
Saccharomyces cerevisiae	6000	13200
Brewers Yeast	3300	6600
Bakers' yeast	3900	8800
Common yeast cake	6000	13200
Mold Spores		
Penicillium roqueforti - green	13000	26400
Penicillium expansum - olive	13000	22000
Penicillium digitatum - olive	44000	88000
Aspergillus glaucus - bluish green	44000	88000
Aspergillus flavus - yellowish green	60000	99000
Aspergillus niger - black	132000	330000
Rhisopus nigricans - black	111000	220000
Mucor racemosus A - white gray	17000	35200
Mucor racemosus B - white gray	17000	35200
Oospora lactis - white	5000	11000

TABLE II

PARAMETER	PURECYCLE OPERATING LEVELS
Nitrate (as N)	<.05
Tubidity (NTU)	.15
Chloride	1
Floride	<.01
Iron	<.01
Magnesium	<.01
Sulphate	<.01
Total Dissolved Solids	2
Zinc	<.01
Total Organic Carbon	<1
Calcium	<.1
Sodium	1
Ammonia	<.01
pH	6
Phosphorous	.01
Conductivity (micromhos/cm)	3
Fecal Coliforms	0
Silica	<.01
Arsenic	<.01
Barium	<.01
Cadminum	<.01
Chromium	<.01
Lead	<.01
Mercury	<.002
Selenium	<.01
Silver	<.01
Copper	<.01
Manganese	<.01
Endrin	<.0002
Lindane	<.004
Methoxychlor	<.1
Toxaphene	<.005
Chlorophenoxys (2,4-D)	<.1
2,4,5-TP Silvex	< .01

Figure 1


Microprocessor
Digestion
Ultrafiltration
Adsorption
Demineralization
Sterilization
Storage



The Process Steps

A Domestic Recycling Sy

Computer C

TREATMENT OF MUNICIPAL WASTEWATER EFFLUENT FOR POTABLE WATER REUSE

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INTRODUCTION

The subject of water reuse has become an extremely important topic in recent years, and it will become even more important as arid regions of the world become more industrialized. Originally, industrial reuse was the major area in which wastewater was treated for recycle and a good review was published by Smith.[1] The largest use of water in industry is for cooling and boiler feed using such sources as secondary effluents of municipal wastewater treatment plants, purified coking wastewaters, and tertiary ponds filled with surface runoff and treated wastewater. Secondary wastewater effluent, following further treatments by coagulation, sedimentation, sand filtration, foam fractionation and carbon adsorption has also been recycled by paper and pulp industries in manufacturing processes.[2]

Recently, treated wastewater has been used for irrigation and groundwater recharge.[3,4] Treatment scheme such as multimedia filtration, aeration, and chlorination has been used on secondary effluents, and the recycled water on many occassion has increased the crop yield, and assured water supply.

An area of water reuse, which has had limited use but becoming more and more important, is that of water reuse for potable purposes. This present study was aimed at developing a treatment scheme which has the potentiality of purifying the secondary effluent sufficiently to insure potability and to test the performance of such a treatment scheme. The treatment scheme, as outlined in Fig. 1, consists of chemical coagulation, sedimentation, sand filtration, reverse osmosis and ozonation.

MATERIALS AND METHODS

Approximately 50 gal of secondary effluent was collected from the East Side Sewage Treatment Plant, Urbana, IL, at the outlet end of chlorination unit as shown in Fig. 2. The secondary effluent was dechlorinated after collection to remove any residual chlorine. The East Side Plant uses primary settling, activated sludge and trickling filters in parallel at a ratio of 3:2 activated sludge to trickling filter, final clarification and chlorination. The typical flow through this plant is 12 mgd and other characteristics of the secondary effluent is summarized in Table 1.

Each of the unit processes, as shown on Fig. 1 was investigated to determine their performance to remove turbidity, TOC, TDS and color. Turbidity was measured in a Hach Turbidimeter Model 2100A (Hach Chemicals Co., Ames, IA) and reported in FTU units. Color was measured in per cent of light absorbed at 360 nm using a Bausch & Lomb spectrophotometer (Bausch & Lomb, Rochester, NY). The electrometric method, using glass and reference electrodes with a Beckman Electromate pH meter (Beckman Instruments, Inc., Palo Alto, CA), was used to measure pH. Total dissolved solid (TDS) was measured using a Yellow Springs conductivity meter (Yellow Springs Instrument Co., Yellow Springs, OH) and the total organic carbon (TOC) measurements were made with a Beckman Model 915 TOC analyzer (Beckman Instruments, Inc., Palo Alto, CA).

The primary purpose for coagulation in the area of water treatment is the removal of suspended solids, and the treatment scheme under investigation is no exception. Aluminum sulfate was used as the coagulant, and it was attempted to reduce the turbidity from an initial value of 6.2 FTU to approximately 1 or 2 FTU. To evaluate the optimum coagulation dose and pH, conventional jar tests were performed using Phipps and Bird flocculator (Phipps and Bird, Inc., Richmond, VA) with one min rapid-mix at 100 rpm followed by 20 min flocculation and 30 min settling. The temperature of water was approximately 20°C. Using the optimum conditions and coagulant dose, as obtained by the jar tests, the secondary effluent was then treated in a simulated laboratory scale coagulation-flocculation unit and allowed to settle for 30 min.

One of the important parameters in the study on water reuse is the removal of organic materials, but very little is known about the ability of chemical coagulation to accomplish this. It is thought that if the organic material is associated with particulate matter, it will be removed well by coagulation-flocculation followed by sedimentation, but if it is in solution, some other process must be employed for organics removal.

The effluent from the settling unit following flocculation-coagulation was filtered through a rapid sand filter bed to remove the solids remaining after the secondary treatment and subsequent coagulation and sedimentation. This was necessary to prevent fouling of advanced treatment processes such as reverse osmosis. The laboratory scale filtration unit was made up of a plexiglass column with 7.62 cm inside diameter. The filter media consisting of 87.0 cm bed of sand of diameter 0.071 cm and porosity 0.425, was supported by a well grounded gravel bed. The filter was operated under constant head with flow rates varying in the range of 0.88 to 1.07 l/min (4.7-5.7 gal/min sq ft).

The filtration effluent was then treated by the reverse osmosis (RO) unit. Reverse osmosis is in principle a relatively simple unit process which separates solutes from a solvent on the basis of differences in molecular size, shape and chemical structure through the use of a semipermeable membrane. The sole energy requirement of the system is the pressurization of the feed solution. This driving force must exceed the osmotic pressure of the solute in order for the separation to be effective. Reverse osmosis is used to separate low molecular weight solutes from a solvent. The complete RO unit, which uses a Dupont B-10 module is shown schematically in Fig. 3. From the head tank, the feed solution was circulated through the test section and by-pass lines with a 5 gpm positive displacement pump. The RO unit was operated at 700 psi and the permeate flux was held constant at 2 gpm.

The RO permeate, having a TDS of 6 mg/l and a TOC of approximately 6 mg/l, mainly consisted of low molecular weight ($MW < 150$) organics. The RO permeate was finally treated with ozone for further removal of organics and disinfection purposes. Ozonation was used as the final unit process of the treatment scheme because of its reported ability as a strong disinfecting agent for resistant pathogenic organisms and good polishing agent for the removal of residual organics. Also, recent findings reviewed by Ajami[5] indicate the formation of undesirable toxic end products when chlorine is used as the disinfectant, whereas non-toxic end products are formed if ozone is the disinfectant.

The laboratory scale ozonation experiments were performed in an agitated vessel reactor, with ozone/air gas mixture flow rate of one l/min. The ozone gas was generated by a Welsbach T-408 laboratory ozonator (Welsbach, Philadelphia, PA) under operating conditions of 60 volts and 8 psig. A preliminary set of ozonation experiments was performed using typical RO permeats to determine the optimum ozonation conditions by varying the following operating perameters:

1) Mixing in the reactor by changing rpm of mixer
2) Initial pH of the RO permeate
3) With and Without ultraviolet irradiation

Flow rate was adjusted such that the detention time in the reactor was 20 min. Flow rate variations were not studied because Chian et al.[6] reported that TOC removal rates are essentially the same for different liquid flow rates of this order of magnitude. UV irradiation along with ozone gas to remove organic contents was studied with the aid of a UV lamp in the reactor, which was a General Electric germicidal lamp with major part of UV energy emitted at a wavelength of 253.7 nm. The lamp was submerged in the reactor fluid for two thirds of its length which resulted in a useful UV dosage of 0.44 watts per liter of reactor fluid.

Aqueous ozone concentration in the reactor was measured by the method developed by Shechter[7] which involves oxidation of a iodine solution and spectrophotometric determination of the tri-iodide ion liberated by ozone at 352 nm wavelength.

RESULTS AND DISCUSSION

The results of the coagulation jar tests on the secondary effluent are presented in Fig. 4, showing per cent remaining of each parameter for varying coagulant dose. The optimum coagulant dose was chosen as 40 mg/l based on the best turbidity and color removal. The best removal (38 per cent) of TOC was from 32 mg/l to 20 mg/l as carbon at 50 mg/l dosage of coagulant whereas at 40 mg/l coagulant dose TOC removal (22 per cent) was from 32 to 25 mg/l as carbon. The difference between the absolute values of TOC remaining at these two doses may not be vary significant because of the fact that the TOC values are accurate to within 2 mg/l using the Beckman 915 TOC analyzer. The best turbidity removal was 41 per cent at 40 mg/l of coagulant dose. An increase in total dissolved solids was recorded due to the fact that alum coagulation removes mainly the particulate matters and some of the alum remains dissolved. TOC and color were removed to the extent of 25 per cent and 65 per cent, respectively, at the optimum dose of 40 mg/l in the jar tests. The results of laboratory scale coagulation experiments, using the optimum dose in the simulated laboratory scale coagulation process, followed by 30 min of settling are presented in Table 2. Per cent removals of turbidity, TOC and color were 78 per cent, 44 per cent and 95 per cent, respectively, through the coagulation flocculation and settling units. It should be noted that at the same dose and experimental conditions the percent removals in larger scale laboratory units were much better than that obtained with the jar tests.

Turbidity removal was the main purpose of the filtration unit and approximately 71.4 per cent of turbidity and 33.3 per cent of effluent color removal were achieved by this unit process. Total dissolved solids were not removed at all by filtration, since filtration is a physical process to remove suspended solids. There was a slight increase in TOC level through the filter bed, this is probably because of the organics present due to improper backwashing in the previous runs. The pH, as expected, remained unchanged after filtration.

The filtration effluent was then treated by the RO unit process. Permeate and retentate volumes through the RO unit were measured so that an accurate estimate of the TOC could be achieved by a mass balance on the total and inorganic carbon. The results of the experiments are presented in Table 3.

The decrease in pH from 6.67 to 5.7 was due to simple acids of low molecular weight diffusing through the RO membrane. Turbidity exhibited a 70 per cent drop while the color was reduced to less than that of distilled water (DW). A 97 per cent reduction of TDS was obtained with the membrane process. As the sensitivity of Beckman 915 TOC analyzer is low for low TOC levels, the TOC of the permeates was obtained by the following mass balance equation,

$$C_fV_f = C_pV_p + C_rV_r$$

where the subscripts f, p and r represent the feed, permeate and retentate solutions, respectively; C, the TOC concentration in mg/l as carbon and V the volume in gal of each solution. Measured values of C_f, C_r, V_f, V_p and V_r were 24, 130, 50, 43, and 7, respectively. From the mass balance, the TOC concentration of RO permeate was calculated as 6.7 mg/l as carbon, which indicates a 72 per cent reduction of TOC.

A preliminary set of ozonation experiments were initially performed on the RO permeate by varying the operating parameters mentioned earlier. The results of the preliminary ozonation experiments are summarized in Table 4.

Based on the preliminary ozonation experiments, following conditions were selected as optimum, for the final ozonation process.

a) Mixing rpm - 500
b) Initial pH - 6.0 or the unadjusted pH of the RO permeate if it is of that order.
c) Without ultraviolet irradiation.

Though the TOC values of the preliminary tests were not very reliable because of their low magnitude but they served as guidelines for the selection of optimum ozonation process. Reliability of the final tests were increased by concentrating the samples for TOC measurements. The samples were concentrated by evapoaration at low temperature (40°C - 60°C) with applied vacuum in flash evaporators. The results of the final ozonation experiments using the optimum conditions are summarized in Table 5 and Fig. 5.

From the final ozonation result presented in Fig. 5, it can be seen that approximately 67 per cent TOC removal was achieved by ozonation within the first five min and then the TOC level remained constant. This observation is to some extent misleading because the TOC of the RO permeate, i.e., the influent to the ozonation process was very low

(6.7 mg/l) and the TOC after ozonation for 5 min reached the value of 2 mg/l which is for all practical purposes very insifnificant and so it should be interpreted that TOC levels of very low order of magnitude was attained within 5 min of ozonation. However, the toxicity of such residual organics after ozonation is yet to be established. Preliminary results using fish toxicity test indicated that the ozonated secondary effluent had no negative effects on fish population if the residual ozone concentration is low or if a short detention time was allowed prior to the use of the treated water.[8] pH was observed to increase with increasing reaction time and reached 6.35 after 20 min starting from pH of 5.7 at the beginning. Such increase of pH may be attributed to the fact that stripping of carbon dioxide in the bicarbonate system is taking place. There was no further reduction of TDS through the ozonation unit and turbidity was reduced to zero.

In a recent investigation at this laboratory to inactivate resistant indicator organisms using ozone Farooq[9] observed 0.1 mg/l of residual ozone for 5 min contact time was sufficient to achieve satisfactory inactivation. In view of this the conditions used for ozonating the RO permeate appears to be sufficient for disinfection purposes.

The overall percent removals of turbidity, TOC, TDS and color through the treatment scheme investigated were approximately 100, 94, 98, and 100 per cent respectively. Fig. 6.

CONCLUSIONS

A tertiary water treatment scheme consisting of coagulation and flocculation, settling, rapid sand filtration, reverse osmosis and ozonation was evaluated to produce potable water from the municipal secondary effluent. The treatment scheme was able to produce a final effluent with total dissolved solids and TOC contents of 17 and 2 mg/l, respectively, which is comparable to that of distilled water. Turbidity and color were reduced to levels below that of distilled water. Thus it may be concluded that a tertiary treatment scheme such as the one described above has the potentiality of producing potable water from secondary effluents.

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TABLE 1

Secondary Effluent Characteristics

Parameter	
Effl. BOD	23 mg/l
Chlorine Dose	7.3 mg/l
pH	7.3
Turbidity	6.2 FTU
TDS	500 mg/l
Color	0.06 Units
TOC	32 mg/l

TABLE 2

Results of Coagulation Experiments

Parameter	Influent	Effluent	% Reduction
Turbidity	6.2 FTU	1.4 FTU	78
pH	7.3	6.5	-
TDS	500 mg/l	550 mg/l	-
TOC	32 mg/l	18 mg/l	44
Color	0.06 units	0.003 units	95

TABLE 3

Results of RO Experiment

Parameter	RO Influent	RO Effluent	% Reduction
Turbidity	0.40	0.12	70
pH	6.65	5.7	-
TDS	550	17	97
TOC	24	6.7	72
Color	0.002	-	-

TABLE 4

Preliminary Ozonation Results
Sample: RO Permeate; Contact Time - 20 mins

Mixing RPM	Initial pH	UV Irradiation	TOC mg/l
500	6.0	No	0.34
500	6.0	Yes	1.15
500	9.0	No	0.82
750	6.7	No	0.98

TABLE 5

Sample: RO Permeate; pH - 5.7; Mixing - 500 RPM

Contact Time min	Dissolved Ozone Concentration mg/l	pH	Inorganic Carbon mg/l	TOC mg/l
0	0.0	5.7	7.0	6.0
5	0.2	6.0	2.0	2.0
10	0.25	6.1	2.0	1.0
15	0.25	6.2	3.0	2.0
20	0.32	6.35	2.0	2.0

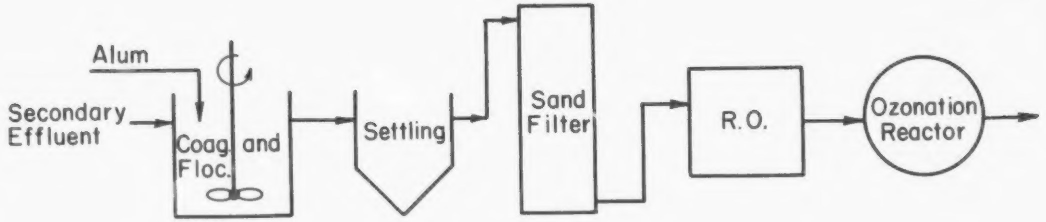


Figure 1 - Schematic Flow Diagram of Tertiary Treatment Scheme for Water Reuse

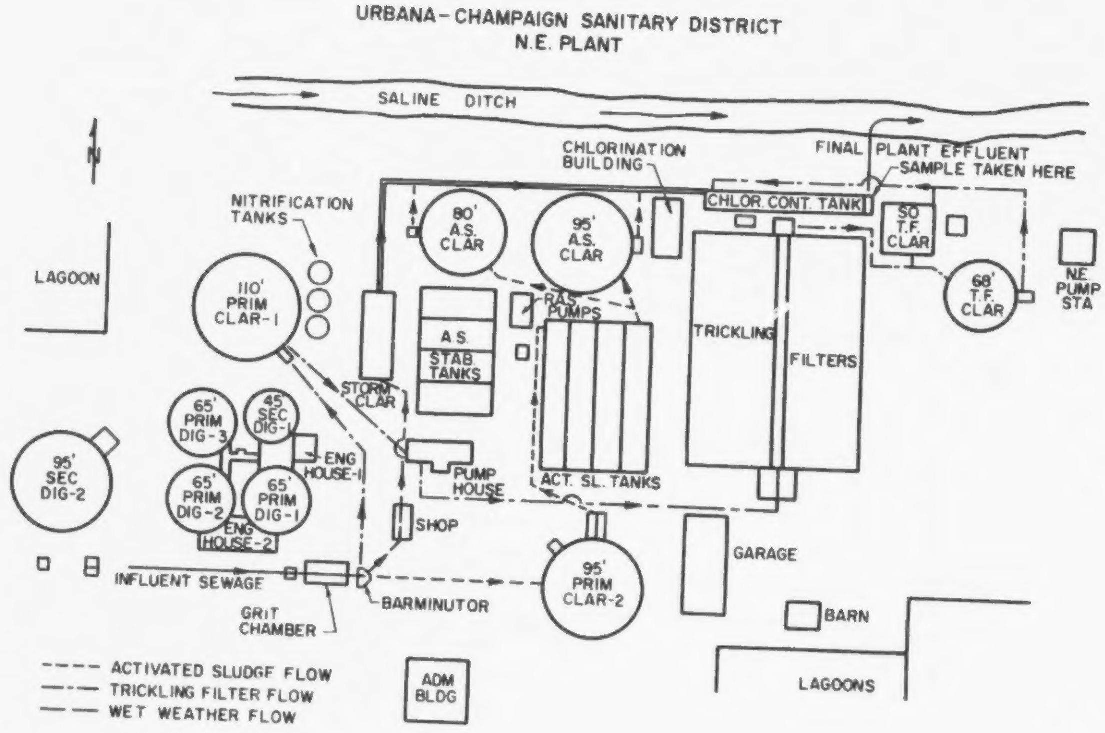
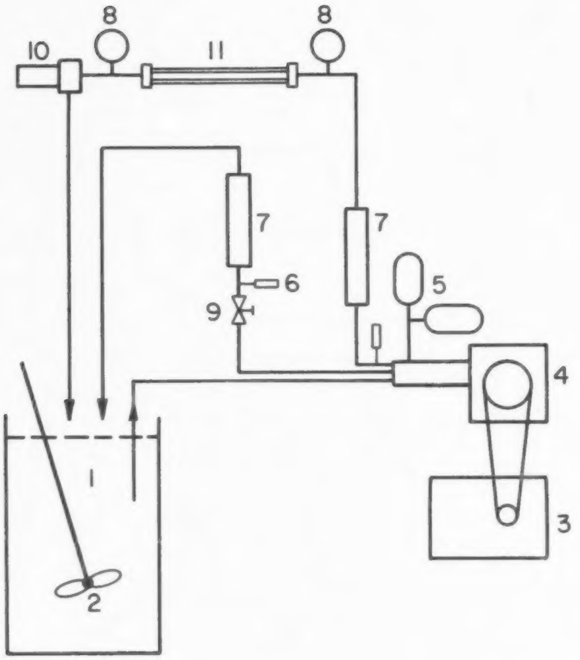


Figure 2 - Schematic Flow Diagram of Wastewater Treatment Scheme and Location of Sampling Point



1. Feed Tank
2. Stirrer
3. 5 HP Motor
4. CAT Pump
5. Accumulator
6. Pressure Relief Valve
7. Flowmeter
8. Pressure Gauge
9. Needle Valve
10. Pressure Regulator
11. RO Test Section

Figure 3 - Schematic Diagram of Reverse Osmosis Unit

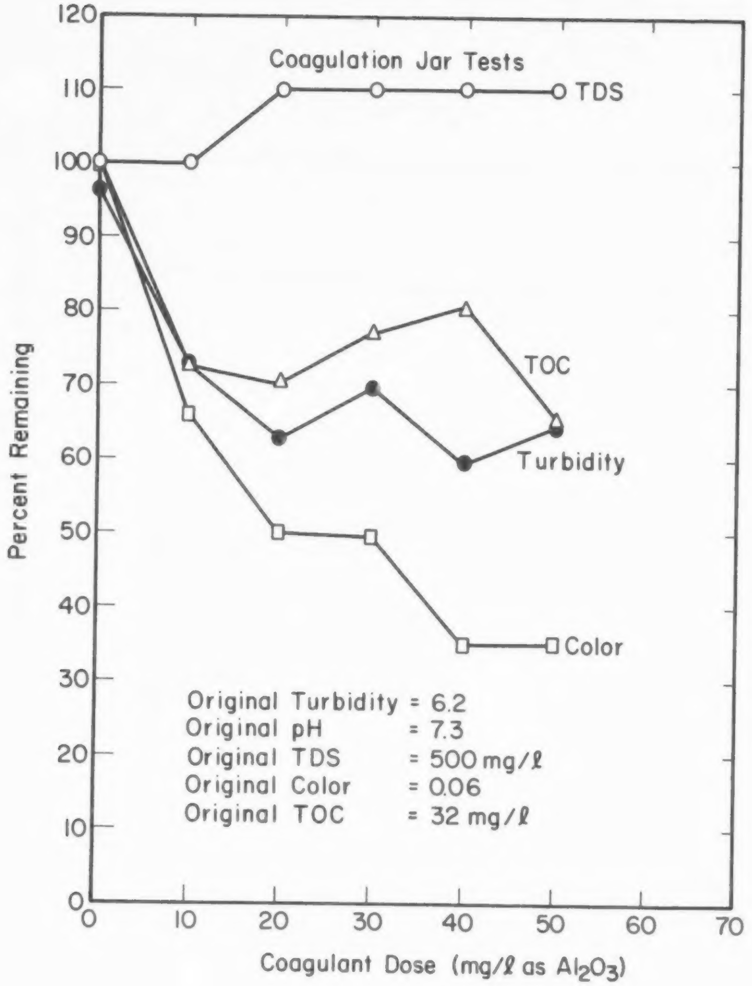


Figure 4 - Performance of Coagulation Jar Test

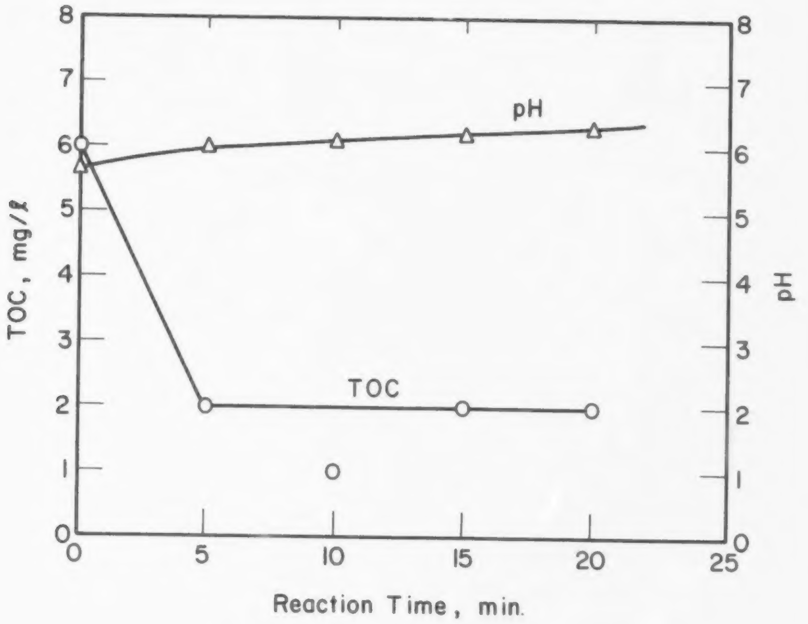


Figure 5 - TOC Removal by Ozonation

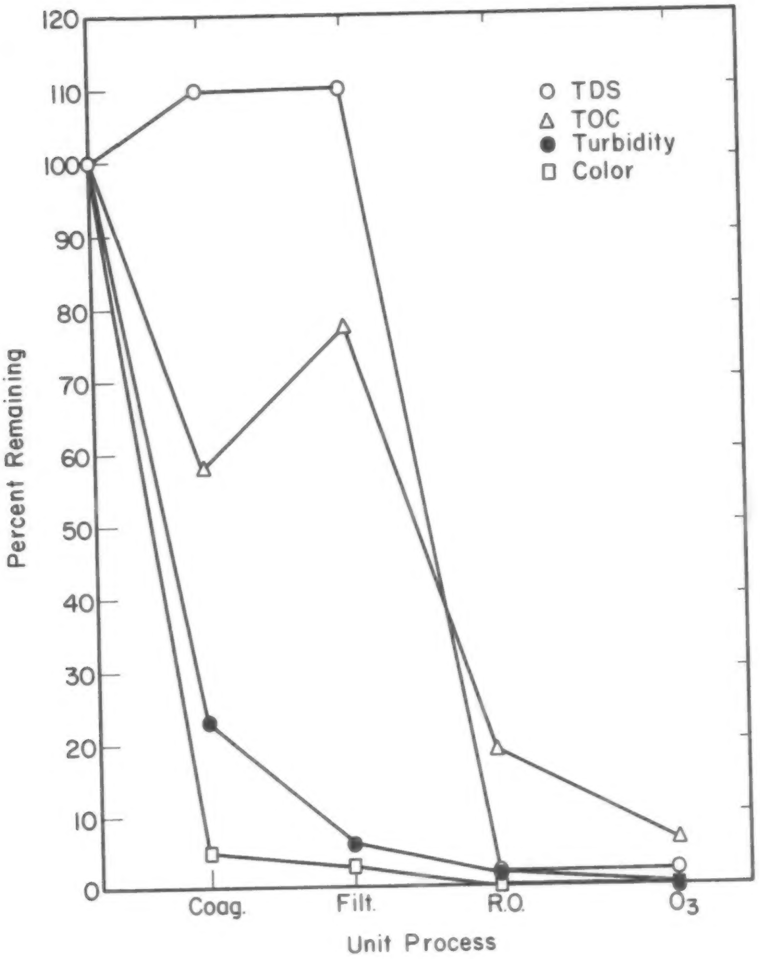


Figure 6 - Overall Performance of Tertiary Water Treatment Scheme

TOWARD THE GOAL OF DIRECT WATER REUSE--
WHAT SHOULD WE DO NEXT?

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It has been quite a few years since the subject of direct water reuse was first brought up in the field of sanitary engineering. However, judging from the number of existing cases of practicing direct water reuse in the entire world, it is reasonable to say that so far the progress in this area has been extremely slow and disappointing. What is the obstacle which has caused a delay in the progress toward direct water reuse--technical or psychological reason? Perhaps someone may even ask why we need to practice direct water reuse. We are not going to practice direct water reuse if we do not have to. It must be understood that direct water reuse is not needed in all localities of the world. It should be limited to such special cases that the amount of naturally available waters are not adequate enough to meet the local demand. As long as there is enough natural water that is of suitable quality and can be obtained consistently within a reasonable cost, there is no need to practice direct reuse. Unfortunately, this is not the case in many parts of the world. Water shortages have been experienced from place to place either perenially or occasionally. The inadequacy of water supplies does not only reduce the quality of life, but often is the major factor that limits the municipal and industrial growths. Under such situations, direct water reuse should be seriously considered to augmet the inadequate natural water resources.

In the United States, the natural runoff averages about 1,200 bgd. The total water demand has increased steadily, from 310 bgd in 1965 to 400 bgd in early 1970's, and to about 500 bgd at the present time. This demand is expected to increase to 1,370 bgd by the year 2020, which exceeds the total available natural runoff. But the real problem of water shortages experienced today is mainly due to uneven distributions of natural water resources. Severe droughts have occurred from time to time in some western United States. To cope with the water shortage problems, direct water reuse may be a much more economical solution than other alternatives such as desalination of sea water or interbasin transfer of fresh water.

TECHNICAL FEASIBILITY

Is direct water reuse technically feasible today? The answer to this question is generally "yes." In the last two decades, significant advances have been made in the water and wastewater treatment technologies. The conventional types of pollutants such as BOD, SS, coliforms, pathogens, nitrogen and phosphorus, etc., can all be removed effectively from wastewater. In fact, some treated effluents may have lower concentrations of these pollutants than those considered satisfactory in raw water sources of domestic water supply, as shown in Table 1 and Table 2. The first table illustrates the high quality effluents obtained by two full-scale advanced waste treatment plants in California and Hawaii, respectively.[1],[2] Comparing these effluent qualities with the general ranges of promulgated standards (Table 2) for raw water sources of domestic water supply (which were promulgated 15 years ago by the U.S. Public Health Service, the New England Interstate Water Pollution Control Commissions, The Interstate Commission on the Potomac River Basin, the Pollution Control Council, Pacific Northwest Area, and the States of Maine, Montana, New Hampshire, New York, Oklahoma, South Carolina, and Utah), one would agree that the treated effluents are either of equal quality or even of better quality in some respects as compared to those considered suitable for serving as raw water sources. Thus, if one took these standards a few years ago as the only criteria for determining the fitness of a water as a source of public water supply, these treated effluents would already be considered satisfactory for reuse after they are passed through a complete cycle of conventional water treatment. In other words, our waste treatment technologies would appear to be advanced enough to allow the practice of direct water reuse.

However, the content of drinking water standards has been subjected to continuous revision, mainly because of the expansion of modern analytical methods which can detect the occurrence of trace impurities in water. Unfortunately, the rate of accumulation of information about the toxicity of these impurities has not kept pace with the modern analytical technics. As a result, extremely conservative precautions have been exercised to apply the contemporary knowledge of toxicology and epidemiology to establish the safe limits of these impurities in drinking water. This may often make the direct water reuse more difficult!

In 1974, the U. S. Congress enacted the Safe Drinking Water Act and, as a result, an Interim Primary Drinking Water Regulations has been promulgated. The water quality parameters included in these new regulations are wider in scope and more stringent in permissible limits as compared to those of the 1962 USPHS Drinking Water Standards. In light of this, determinations of the "appropriateness" of direct water reuse should be based on the comparison of the treated effluent qualities with the newly promulgated regulations. Unfortunately, current practice of municipal waste treatment has not included comprehensive water quality analysis as that required for drinking water. Therefore, in order to obtain a precise answer on the question of the current technical "maturity" toward direct water reuse, immediate efforts must be taken to expand the scope of the effluent quality analysis. Nevertheless, at the present time it is felt that a complete treatment scheme, as shown in Figure 1, using some of the currently available advanced waste treatment technologies should be able to produce a water of sufficient quality for direct domestic reuse.

MAJOR OBSTACLES TOWARD DIRECT WATER REUSE

What is the major obstacle for the public to accept direct water reuse today? It is the "psychological unreadiness!" For a long time, the word "wastewater" has been invariably linked with a psychological implication of "filth" and "dirtiness" no matter how well it has been treated. Although there is concrete evidence that impurities and harmful substances can be removed from wastewater by today's treatment technologies, the public has not been convinced, and the sanitary engineering profession has not actively been trying to convince them either, that the properly treated effluent can be reused for domestic purposes. In fact, many people have been deeply imbedded with such an attitude that "if no one dares to drink the sewage effluent first, I will not be the first one to try!" But if there is some "daredevil" who is willing to try the sewage effluent, are other people likely to follow in his footsteps? The answer to this question is a definite "yes."

Here are three specific examples that the author himself had encountered:

Example 1: On June 29, 1973, when Hawaii's first advanced waste treatment plant, the Ahuimanu Plant, was dedicated, a total of about 100 individuals representing different sectors of the public were invited to participate in the event. Before the dedication ceremony everyone present was overwhelmingly impressed with the absolute clarity of the treated effluent--just like tap water--but no one was willing to try to drink it when he was asked to. At the end of the ceremonial address, the design engineer of the plant took a bold step by making a toast to the participants with the plant effluent. Because of his voluntary move, a total of more than 20 individuals, including TV reports and camera men, were either curious or brave enough to try the same effluent that day. Most important of all, none of these individuals had shown any subsequent illness.

Example 2: In April 1975, the author was invited to give a talk to the Science Club of West Plains High School in Missouri. The topic was on the "Feasibility and Risks of Drinking Sewage Effluent!" In connection with the talk, the author brought with him two large bottles of tap water, but one was intentionally labelled as "sewage effluent" while the other was correctly identified as "tap water." At the end of his talk, the author emphatically pointed out to his 40 high school students that the "sewage effluent" had been thoroughly treated in the Sanitary Engineering Research Laboratories at the University of Missouri-Rolla, and that there was absolutely no risks or danger involved in drinking such a sewage effluent sample. He then asked for any volunteer from his audience who was willing to try such an effluent first. But for about five minutes the students were looking at each other and jokingly trying to volunteer other fellow classmates to make such a first move. There was no single individual who was willing to step out and give it a try. Finally, the author had to "volunteer" himself to take the first drink. Ater his first voluntary move, more and more students came up to the podium and asked for a try of the "sewage effluent." Within about 15 minutes, all of the 40 students had already tried the "sewage effluent," at least a half-glass full of it. No one appeared to have any reluctance! This episode clearly reflects that the public psychological barrier, even among our youngsters, is the major obstacle that has delayed the progress of direct water reuse. Most people still have a feeling that "if no one is willing to drink the sewage effluent first, I am not going to be the first one to try!"

Example 3: The author participated in an international conference on advanced treatment and reuse of wastewater, which was held in Johannesburg, South Africa, in June 1977. As part of the conference program, the participants had an opportunity of visiting the Stander Water Reclamation Plant in the outskirts of Johannesburg. This treatment plant had 4,500 m /d full-scale facilities consisting of conventional secondary treatment plus ammonia stripping, recarbonation, chemical clarification, chlorination/ozonation, and carbon adsorption. The treated effluent was told to be of potable quality. It was a "traditional custom" for visitors to drink the plant effluent and log their names on a book. Since the book had already carried thousands of names in it, none of the 300 conference participants seemed to be hesitant to try the plant effluent. Of course, the willingness of this international professional group to drink the sewage effluent would reflect their confidence in today's technical readiness for direct potable reuse.

The above three examples apparently suggest that there exists a considerable psychological barrier in the society toward direct water reuse. To overcome this barrier, some one has to volunteer his confidence in direct water reuse so that others will follow him. But who should be the one to volunteer? Logically, it should be the professional group who is actively involved in the treatment of water and wastewater.

STEPS TO OVERCOME THE PSYCHOLOGICAL BARRIER

As mentioned earlier, the most important obstacle for the public to accept direct water reuse is the "psychological unreadiness." This is because for a long time the words of "sewage" and "wastewater" have been linked with a sense of "filth," "dirtiness" and "unwholesomeness." The public is not aware of the fact that almost all of the impurities in wastewater can be removed by today's advanced waste treatment technologies. In order to overcome this deeply-rooted psychological rejection, or at least reluctance, toward direct water reuse, intensive public education plus enthusiastic professional campaign are necessary so that the public can be convinced that wastewater, like a piece of equipment or other merchandise, can be "repaired" or "renovated" to make it clean and wholesome again.

In carrying out the public education and professional campaign, the following actions should be seriously considered:

1. Consideration should be given to change some of the common terminologies used today which either explicitly or implicitly link wastewater with a sense of feeling of filth and dirtiness, such as:

Existing Terms	Suggested New Terms
Wastewater or sewage	Used water (making it synonymous to used car or other merchandise that can be fixed and reused)
Waste Treatment Plant	Water renovation plant or water reclamation center
Treated Sewage Effluent	Renovated water, or reclaimed water
Sewage Sludge	Municipal Humus
Sewage Treat Plant Operator	Water Renovator

The main objective of using the above new terminologies is to impress the public that "wastewater" is just like a "used car" or a "used typewriter," that can be fixed and reused. It is hoped that with these terminologies, the public will gradually be convinced that wastewater is really not that bad at all. It is only temporarily "used" and can be reused again after it is cleaned up.

2. The public must be informed clearly that "water reuse" is not new at all. We have been reusing our wastewaters for decades! For an American city experiencing only average reuse of its surface supply, one-half of its water has passed through a municipal or industrial outfall. For other cities in the upper 10% reuse bracket, their supplies have been used at least three times previously. Of course, the current reuse is neither deliberate nor direct; it merely occurs from one community to another as water flows downstream through surface or underground drainage systems. However, in any dry season, most of the water in a natural stream may be from municipal sewage effluents. Under such an extreme situation, a practice of "direct reuse" has already been in effect!

3. The sanitary engineering professional group should take a lead to publicize the fact that today's advanced water and wastewater treatment technologies are absolutely able to convert wastewater to potable one. They should also take a lead to demonstrate their willingness of drinking the treated sewage effluent first.

4. More intensive research must be undertaken immediately to assess the real toxicological implications of the various impurities present in wastewater effluent. At the present time our knowledge in this field is still in the stage of infancy. Because of this, many new standards established today may be unduly conservative. This definitely makes direct water reuse more difficult. It must be pointed out here that in many underdeveloped countries, people are still drinking water from fairly polluted sources without having adequate treatment. Yet there is still no concrete evidence that these people have some kinds of chronic toxicity (except bacterial and viral infections) that can be linked directly with the chemical impurities present in their polluted drinking waters.

Since the toxicological implications of various impurities may not be able to define precisely in a foreseeable future, it is suggested that a thorough scientific investigation be initiated by the government to make a statistical correlation between the "drinking water qualities" and the resultant "chronic toxic effects," if any and if identifiable, in some underdeveloped countries. This will help us to determine the advisability of establishing more stringent drinking water standards in the future.

SUMMARY

The subject of direct water reuse has been traditionally more personally sensitive and touchy than other scientific topics. The public outright rejection, or at least reluctance, of accepting direct water reuse is mainly due to a long-standing psychological linkage between wastewater and dirtiness.

It is felt that as long as there is enough natural water in a local area to meet its demand, there is no reason to practice such a reuse. The presence of a "natural barrier" in a receiving stream is invaluable to give a first warning sign of any potential toxicity to be encountered in the public water supply. However, in some arid areas or island countries in the world, direct water reuse is often more economical than direct desalination of ocean water. Under such circumstances, it is suggested that serious considerations be given to direct water reuse. In the United States, the public is not psychologically ready to accept such a practice today. But current available advanced treatment technologies should be able to produce effluents of such a high quality that they would be relatively harmless to drink despite some "uncertainties" that no one can really give a definite answer. At the present time, it is apparent that the public's psychological barrier outweighs the technical credibility toward the reuse application. Because of this, a lot of public education and professional campaign is still badly needed.

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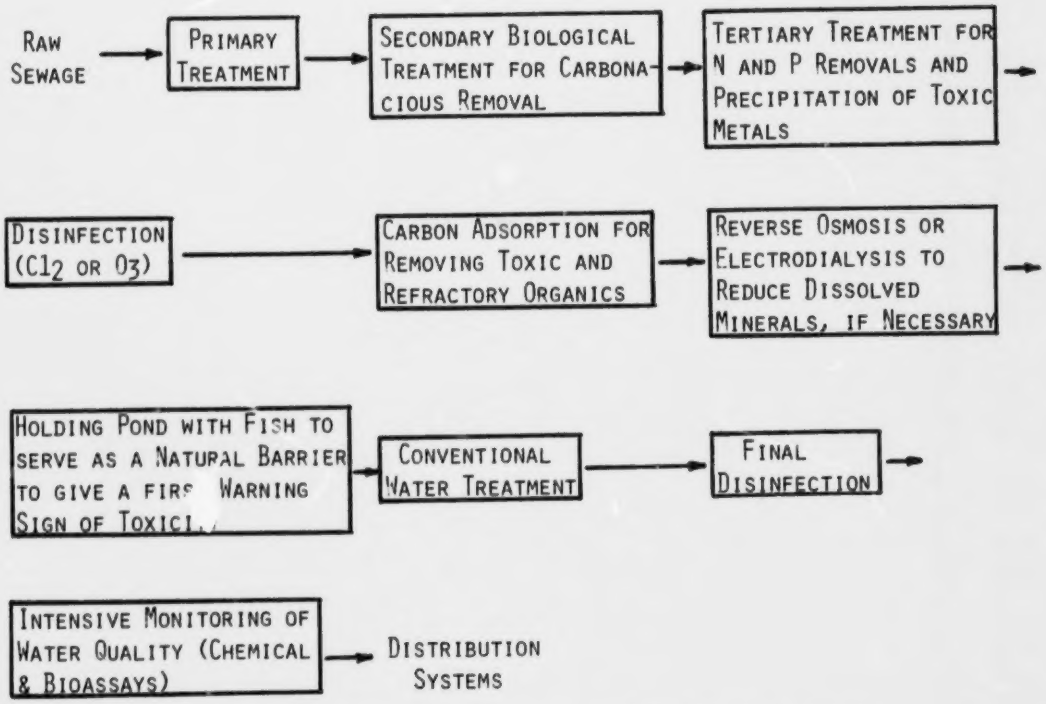
RAW SEWAGE
PRIMARY TREATMENT
SECONDARY BIOLOGICAL TREATMENT FOR CARBONACIOUS REMOVAL
TERTIARY TREATMENT FOR N AND P REMOVALS AND PRECIPITATION OF TOXIC METALS
DISINFECTION (Cl2 OR O3)
CARBON ADSORPTION FOR REMOVING TOXIC AND REFRACTORY ORGANICS
REVERSE OSMOSIS OR ELECTRODIALYSIS TO REDUCE DISSOLVED MINERALS, IF NECESSARY
HOLDING POND WITH FISH TO SERVE AS A NATURAL BARRIER TO GIVE A FIRS WARNING SIGN OF TOXICI.
CONVENTIONAL WATER TREATMENT
FINAL DISINFECTION
INTENSIVE MONITORING OF WATER QUALITY (CHEMICAL & BIOASSAYS)
DISTRIBUTION SYSTEMS

Figure 1. Treatment Schematic To Achieve Reusable Water

TABLE 1

Treatment Efficiencies Achievable By Two Advanced Plants

Effluent Parameters	South Tahoe Plant, Calif.		Ahuimanu Plant, Hawaii	
	Effl. Conc.	Efficiency, %	Effl. Conc.	Efficiency, %
PH	6.8 - 8.7	-	7.0 - 7.8	-
BOD_5 $(\mathrm{mg}/_{l})$	1	99.6	3	98.7
SS $(\mathrm{mg}/_{l})$	0	100	1	99.6
Total Nitrogen $(\mathrm{mg}/_{l\,-\,N})$	-	-	0.09	97.0
Total Nitrates $(\mathrm{mg}/_{l\,-\,N})$	-	-	3.3	-
Total Phosphorus $(\mathrm{mg}/_{l\,-\,P})$	0.6	99.6	1.5	90.3
Total Coliform $(\mathrm{MPN}/_{100ml})$	< 2.0	99.9+	< 43	99.99+
Virus Recovered (PFU)	0	100	-	-
Dissolved Oxygen	-	-	≥ 6	-

TABLE 2

Ranges Of Promulgated Standards For Raw Water Sources Of Domestic Water Supply

Constituent	Excellent Source Requiring Disinfection Only	Good Source Requiring Usual Treatment	Poor Source Requiring Special or Auxiliary Treatment
PH, Average	6.0 - 8.5	5.0 - 9.0	3.8 - 10.5
BOD_5, $mg/_1$			
Monthly Average	0.75 - 1.5	1.5 - 2.5	Over 2.5
Maximum Day	1.0 - 3.0	3.0 - 4.0	Over 4.0
Coliform, $MPN/_{100\ ml}$			
Monthly Average	50 - 100	50 - 5,000	Over 5,000
Maximum	Less Than 5% over 100	Less Than 20% over 5,000	Less Than 5% over 20,000
Dissolved Oxygen, $mg/_1$			
Monthly Average	4.0 - 7.5	4.0 - 6.5	4.0
% Saturation	75% or Better	60% or Better	-
Chlorides, $mg/_1$	50 or Less	50 - 250	Over 250
Fluorides, $mg/_1$	Less Than 1.5	1.5 - 3.0	Over 3.0
Phenolic Compounds, $mg/_1$	None	0.005	Over 0.005
Color, Units	0 - 20	20 - 150	Over 150
Turbidity	0 - 10	10 - 250	Over 250

WATER REUSE
SYMPOSIUM

INDUSTRIAL RECYCLING AND REUSE

THE CONTRA COSTA RECLAIMED WATER PROJECT
- AN UPDATE -

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INTRODUCTION

The Contra Costa Reclaimed Water Project is a cooperative venture between the Contra Costa County Water District (CCCWD) and the Central Contra Costa Sanitary District (CCCSD). The project, presently at the startup and testing phase, is located in central Contra Costa County, California. When in full operation the facilities will provide pollution control through a 40 mgd waste treatment plant and produce up to 30 mgd of filtered and softened reclaimed wastewater for cooling use by industries. A description of CCWD's portion of the project is contained on Plates 1 and 4.

Implementation of the project from concept through research, pilot studies, demonstration projects, funding, repayment arrangements, design, construction and now integration of reclaimed water into water resource and waste resource management for a society with changing and evolving priorities and policies, requires a multitude of technical and institutional consideration and a dynamic planning process.

BACKGROUND INFORMATION

Contra Costa County (CCC) has a population of over 500,000 and it has the largest concentration of heavy industry (oil, chemicals, steel and paper) in Northern California. It is located at the junction of the San Francisco Bay and the Delta of the Sacramento and San Joaquin Rivers. Municipal and Industrial water supplies for the County are provided by the East Bay Municipal Utility District (EBMUD) and the Contra Costa County Water District (CCCWD). EBMUD imports water to the western and southwestern portion of Contra Costa County from the Mokelumne River in the Sierra Nevada Mountains along the eastern edge of California. CCCWD purchases water for the central and northeastern portions of Contra Costa County including the central county heavy industrial complex from the Federal Central Valley Project. This water is diverted from the Sacramento-San Joaquin Delta within Contra Costa County and delivered through the Contra Costa Canal System.

Central Contra Costa Sanitary District (CCCSD) provides sub-regional wastewater treatment and disposal for the southwestern and central portions of Contra Costa County, and presently discharges nearly 30 mgd of treated effluent into Suisun Bay. Sewered areas tributary to the CCCSD treatment facilities overlap areas with water supplied by EBMUD and CCCWD. Studies in the early 1960's showed that CCWD would require additional water supplies, and that the conveyance

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capacity of the Contra Costa Canal System (pumping plants, tunnel and canals) would be inadequate by the early to mid-1970's. A significant portion of the District water supply was transported 25 miles from the intake to the Central County area where heavy industries used nearly 30 mgd. District staff and consultants studied desalting, groundwater, and reclamation of domestic sewage as potential additional sources of supply. CCCSD had adequate wastewater and their facilities were located near the industries considered as potential markets for reclaimed water.

With the passage of Federal and State Water Quality Control and Clean Water Acts in 1965 and 1966, it became necessary for CCCSD to plan improvements for upgrading treatment as well as expanding their facilities. Regional planning efforts for wastewater treatment and disposal and an emerging federal and state wastewater reclamation policy created circumstances in which both districts, CCCWD and CCCSD, would benefit if the wastewater could be reclaimed; CCCSD through expanded grant funding and revenue from the sale of its effluent, and CCCWD through delaying, perhaps indefinitely, enlargement of the Contra Costa Canal System.

To appreciate the value of wastewater reclamation in central Contra Costa County, the quality of water from the several sources is presented below (mg/l - averages):

Constituent	CCCWD Water	EBMUD Water	Reclaimed Water Straight	Reclaimed Water Softened
Calcium	25	7	65	5
Magnesium	16	1	16	2
Sodium	55	1	115	212
Alkalinity	73	18	123	123
Sulfate	62	1	116	116
Chloride	67	2	124	124
Nitrate	7.5	.1	94.5	94.5
Silica	15	9	13	13
Tot. P	0.6	.05	0.7	0.7
TDS	306	32	630	653

About one-half of the wastewater originates in the area served by EBMUD with water that originates in the Sierra Nevada. This is high quality water and without it the wastewater would be much higher in TDS, hardness, and chlorides, making it much more difficult, and expensive, to reuse the water.

INSTITUTIONAL CONSIDERATIONS

In 1969, a memorandum of understanding was signed between CCCWD and CCCSD. That memorandum established that CCCSD was responsible for liquid and solid waste management and that CCCWD was responsible for water resource management in the central county area. The memorandum further defined specific investigations and research and development programs, and the development of implementation plans for municipal refuse and sludge disposal, wastewater renovation, and water pollution control. Based on this agreement and to maintain long term grant eligibility, a FWQA Pilot and Demonstration grant was transferred from CCCWD to CCCSD and joint studies begun. Between 1969 and 1971 CCCWD and CCCSD spent $633,146 on the development of reclaimed water, compared with the FWQA funds of $322,250.

At this point, several setbacks occurred, any one of which could have been used to abort the project. During 1971, we learned that under the Federal Water Pollution Control Grant program, advanced treatment, that is, beyond secondary effluent to meet waste discharge levels, was not grant eligible. Our consultants informed us that advance treatment facilities such as filtration, clear well, etc., would cost approximately $16 million. Rather than let the project die, the Water District went to Congressman Biz Johnson and Senator Muskie, both members of the Conference Committee on Amendments to the Pollution Control Act. Simply stated, the approach was, "If the United States spends billions of dollars of taxpayers' grant money to treat sewerage up to roughly secondary levels and then throw it away, why not spend a few more dollars, thereby protecting your initial investment and realizing true water re-use?" By letter of June, 1971, Congressman Biz Johnson wrote to CCCWD:

> "The only amendment added to the Pollution Control Act of this year was yours, that extended grant eligibility for the advance treatment facilities such as filtration, clear well and transmission main."

On November 10, 1971, the State Water Resources Control Board mandated that certain conditions precedent must be met for grant eligibility certification.

First: both agencies must negotiate and execute a long-term agreement specifying service area, quantity, quality and price of re-use water, along with respective operation and maintenance responsibilities. A committee consisting of two board members of each agency, supported by staff, through many challenging meetings, accomplished that assignment and in April, 1972, the Reclaimed Water Supply Contract was signed. This contract contained the following significate points:

- The quantity of reclaimed water to be delivered is that which the Water District needs, not to exceed 30 million gallons per day or that amount which can be produced by the Sanitary District, whichever is lesser.

- The Water District has first and prior rights to purchase the reclaimed water except that water in excess of Water District needs may be sold or disposed of outside of the territory of the Water District.

- The reclaimed water must meet the following water quality standards: TDS 375 mg/l; Hardness 300 mg/l; Alkalinity 255 mg/l; Cl_2 residual 0.5 mg/l; Coliforms 2/2 MPN/100 ml pH 6.5 to 8.5; Turbidity 3 JTU; BOD_5 10 mg/l; TOC 20 mg/l; Total Phosphorus 1 mg/l; Total Nitrogen 5 mg/l.

- The water quality measuring points, measuring frequency constituents and analytical methods are specified.

- The Water District retains the right to review and comment on facility designs prior to approval of final design by the Sanitary District.

- The Water District agreed to construct delivery facilities to its customers.

- A specific point for delivery of reclaimed water to the Water District was designated.
- Operation and maintenance responsibilities are defined.
- A price of $3.50 per acre foot.
- If quality standards are not met, the price can be decreased to offset the increased costs incurred by the users.
- The contract runs through June 30, 2006.

Second: CCCWD must guarantee a market for reclaimed water. Originally, CCCWD had promoted the use of reclaimed water for all industrial uses. However, feedback from the industries clearly demonstrated that for uses other than cooling towers, excessive penalty costs (operating costs over and above those incurred with normal source water) would result from the use of reclaimed water. Potential industrial customers were reluctant to even consider using reclaimed water for cooling purposes.

The District adopted a regulation, Plate 5, stating that, if reclaimed water were made available to an industry for cooling purposes by the District, the District would not sell canal water to that industry for cooling. This regulation, the first of its type, found its way into Congressional Records. The effect of this Regulation was to force the industries to seriously consider the use of reclaimed water. Serious and intense dialogue between CCCWD and the industries began with adoption of the Regulation and resulted in an informal commitment by CCCWD to determine the industrial costs associated with the use of reclaimed water for cooling and to consider those costs in the ultimate price for reclaimed water. CCCWD promised to explore the possibility of additional treatment of reclaimed water to tailor it to industrial cooling use.

Third: CCCWD must amend its water supply contract with the U. S. Bureau of Reclamation to allow the substitution of reclaimed wastewater for CVP water in CCCWD's service area. The Bureau's position, from the Regional Director in Sacramento to the Commissioner in Washington, was that we must pay for their water on the annual contract buildup schedule, even though we used reclaimed water. Estimated payment to the United States over the buildup period was in the order of $14 to $16 million. Needless to say that this type of dual cost would have aborted the re-use project.

We turned to Secretary of the Interior, who listened to CCCWD's arguments reciting the spirit and intent of the Federal Water Quality Act, and the national policy to encourage the re-use of water, and specifically the need for U.S.B.R. to expand their concept of the CVP to accomodate our re-use program within our long term water supply contract. Negotiations began with the Bureau of Reclamation to amend our agreement providing for the U.S.B.R. contract payment deferral necessary to offset the quantity of reclaimed water used. The amendment to our USBR Water Supply Contract was signed in April, 1973. The net effect of this amendment is to defer payment of $9 for each acre foot of reclaimed water developed.

In June of 1973 the California Regional Water Quality Control Board, San Francisco Bay Region, adopted Order No. 73-41 prescribing wastewater reclamation requirements for the CCCSD, and CCCWD, and the specific industries that would use the water.

Design, additional testing and demonstration programs, and construction began and the project appeared defined and headed for completion. The CCCWD had taken the position that reclaimed water would be an expansion of the District's total water supply, not an independent industrial supply with the costs to be borne only by the involved industries. The base cost to the industrial user of reclaimed water would be the same as for Canal water, with an adjustment for any significant difference in the utility (costs for use and disposal) between canal water and reclaimed water. Thus the costs for reclamation would be spread over all District water consumers. An on-site testing program was conducted, and CCCWD's consultant determined the user cost associated with use of the reclaimed water. The results indicated that industry costs would be higher using reclaimed water, but lower or about the same if the reclaimed water were tailored to cooling use. CCCWD's engineering consultants recommended a selective demineralization, treatment process called SANAX (strong acid-sodium exchange). Just about the time the SANAX process was well along in design, EPA and the local Bay Regional Board decided that even though the Central Sanitary District was constructing a full nitrification/denitrification system, they need not denitrify for discharge to the Bay. Denitrification may be required in the future. The CCCWD/CCCSD agreement specified denitrification and industry expected and insisted on a denitrified product.

To provide CCCWD with a denitrified product would have imposed an annual operating cost on CCCSD in the order of $800,000. In spite of the fact that the re-use customers required denitrification and the CCCWD/CCCSD contract required it --- reason prevailed, and the two Districts amended their agreement, deferring denitrification until future requirement by the regulatory bodies. The amendment contained the following significant points:

- CCCWD to accumulate and maintain reserve fund as required by State and Federal Guidelines for maintenance, repair, replacement, and renewal of facilities built by CCCSD for operation and maintenance by CCCWD.
- A price of $4.00 per acre foot with a minimum annual amount.
- Nitrogen limit of 5 mg/l excluded from price adjustment provisions and removed from quality provision of agreement.
- CCCSD to lease lands to CCCWD for reclaimed water treatment facilities.
- CCCWD to have right to use CCCSD outfall for discharge of light waste from softening or other reclaimed water treatment facilities.

Following changes in Regional Water Quality Control Board regulations concerning the NPDES permit for CCCSD and agreement to drop denitrification from the treatment process, it was necessary to drop the SANAX treatment alternative and use simple sodium softening. The change in alkalinity of reclaimed water when not denitrified was the primary cause of this change.

At this point in the project, construction was complete on some units of CCCSD's facilities and well underway on all phases except CCCWD's softening plant. The physical facilities to treat the wastewater and to soften and deliver the reclaimed water are designed to handle 30 mgd, the softening plant is being built in 15 mgd units. The Reclaimed Water Project components are:

The treatment facilities provided by the Sanitary District include:

- Chemical primary treatment with lime.
- Biological nitrification.
- Sludge incineration.
- Filtration.
- Clearwell and transmission pipeline (CCCWD O&M)

The facilities provided by the Water District include:

- Ion exchange softening plant (15 mgd)
- Storage tanks
- Distribution system pipelines, metering facilities, etc.

TOWARD THE FUTURE

At this time the facilities are essentially complete; however, the project is dynamic and must be managed accordingly. The future holds significant challenges, questions, and unresolved issues.

The California Regional Water Quality Control Board, San Francisco Bay Region is reviewing the Water Reclamation requirement for the Project. The Tentative Order includes contingency planning requirements which were not specifically considered during design, together with new monitoring, reporting, and documentation requirements.

CCCWD must finalize reclaimed water rules and regulations. They must reflect the dual supply, reclaimed water and canal, to each industry. Rates for reclaimed water must also be set.

A unique combination of public service responsibilities of CCCSD and CCCWD, together with the integrated utility operations require a close working relationship to achieve and to maintain the goals of the original memorandum of understanding between the two Districts.

The 1976-77 drought verified potential risks identified early in the project by CCCWD:

- The close inter-relationship between water conservation goals and reclamation goals and the potential for counter productivity if attempts are made to individually maximize these goals. The current trend at state and federal levels to maximize both conservation and reclamation must be watched closely.

- The importance of the quality of water supplied by EBMUD and CCCWD to the area sewered by CCCSD to the economics of water reclamation. During the 1976-77 drought period conservation programs by CCCWD and EBMUD significantly reduced CCCSD influent at the same time the quality of CCCWD and EBMUD waters deteriorated. Analysis of data collected during the early portion of the drought and the impact on the reclaimed water project showed that the combined impact would reduce the cycles of concentration in the cooling towers from 9.0 during normal operation to 7.2 during drought operations. The water requirements would increase slightly while the blowdown (industrial wastewater requiring treatment before discharge) would increase by about 66%.

- The value of re-use as a means of reducing the impact of drought on the overall water supply at CCCWD. Even though the utility of reclaimed water would be reduced by drought related activities, a significant base influent to CCCSD could be maintained and the overall impact of a drought reduced. At present levels of development reclaimed water (15 mgd) represents about 15% of CCCWD's normal high quality water requirements, or 25 to 30% of the total surface water imported into the CCCSD service area.

  The drought also emphasized the potential for water conservation and demand management as resource management tools. CCCWD is currently developing a policy on this subject, which will consider the potential impact on reclamation and may change the District's goals in that area.

The evolving changes in federal and state policy toward water projects, water rights, and funding will impact the planning for expansion of the Project and even its operation.

CONCLUSION

Our experience demonstrates that the basic criteria for a wastewater renovation and re-use program is as follows:

A. A high quality domestic water delivered to a highly urbanized area, with close proximity to potential users (industrial, open space or agricultural).

B. A water supply agency that faces the need to augment water supplies and/or transmission facilities, and

C. A strong Board of Directors and staff who are willing to take the risks and make decisions way beyond the term of their respective offices.

That criteria, in my judgment, fits most of the nine Bay Area counties, as well as other urban/industrial water use areas in the state and the nation.

~~Plate 1~~

CONTRA COSTA COUNTY WATER DISTRICT

RECLAIMED WATER PROJECT

FACT SHEET

Water Use:	Industrial Cooling Towers
Scheduled Operation:	Summer, 1979
Capacity:	30 MGD
Initial Delivery:	12 - 15 MGD

Water Users:

- Lion Oil Co. - Avon Refinery (Formerly Phillips Petroleum)
- Shell Oil - Martinez Refinery
- Stauffer Chemical - Martinez
- Monsanto Chemical - Avon
- P. G. & E. - Avon
- P. G. & E. - Martinez

Agencies:	Contra Costa County Water District (CCCWD) Central Contra Costa Sanitary District (CCCSD)
Consulting Engineers:	James M. Montgomery (CCCWD) Brown & Caldwell (CCCSD) Bechtel (CCCSD)
Institutional Arrangement:	Contract between CCCWD and CCCSD

Major Contract Items:

1. CCCSD produces reclaimed water in accordance with contract quality requirements.
2. Price of reclaimed water to CCCWD is $4.00 per acre foot. Contract provides for increase or decrease in price contingent on water quality.
3. CCCWD purchases reclaimed water from CCCSD, softens it, and distributes it to user industries. Price to industry is not specified in contract.
4. The term of the contract is through June 30, 2006.

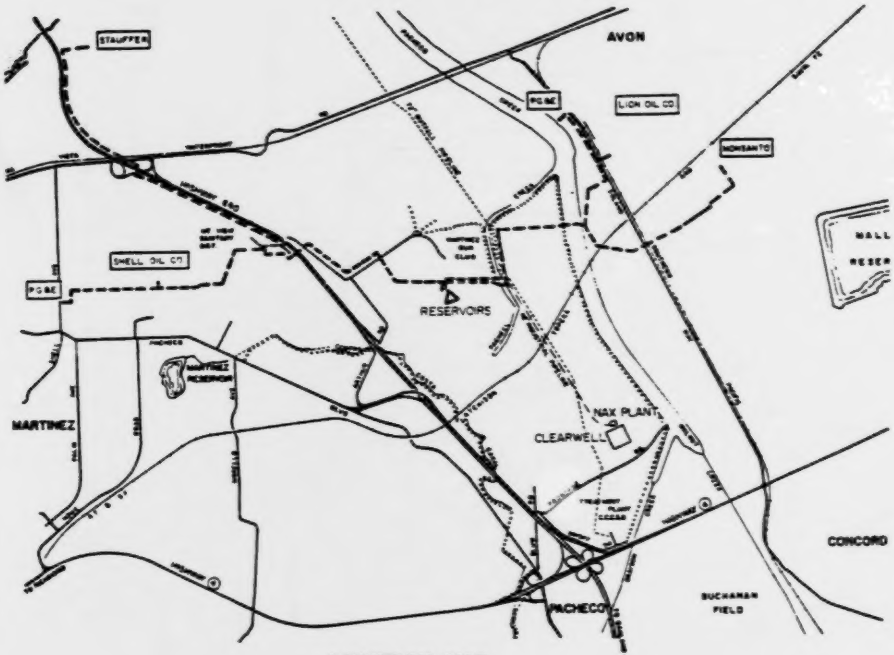
Upon completion of the project in 1979, this joint CCCWD/CCCSD operation will supply about 15 MGD peak demand of reclaimed water to six industrial customers, located between Martinez and Port Chicago, for use as industrial cooling water. The six industrial users presently receive about 30 MGD of raw water from CCCWD for their total industrial needs, which include cooling, low and high pressure boiler, process, wash-down, and fire protection. The reclaimed water will replace 15 MGD peak demand of the cooling water use. The project is designed to ultimately meet a 30 MGD demand by industrial users.

Plate 2

CCCWD Facilities:

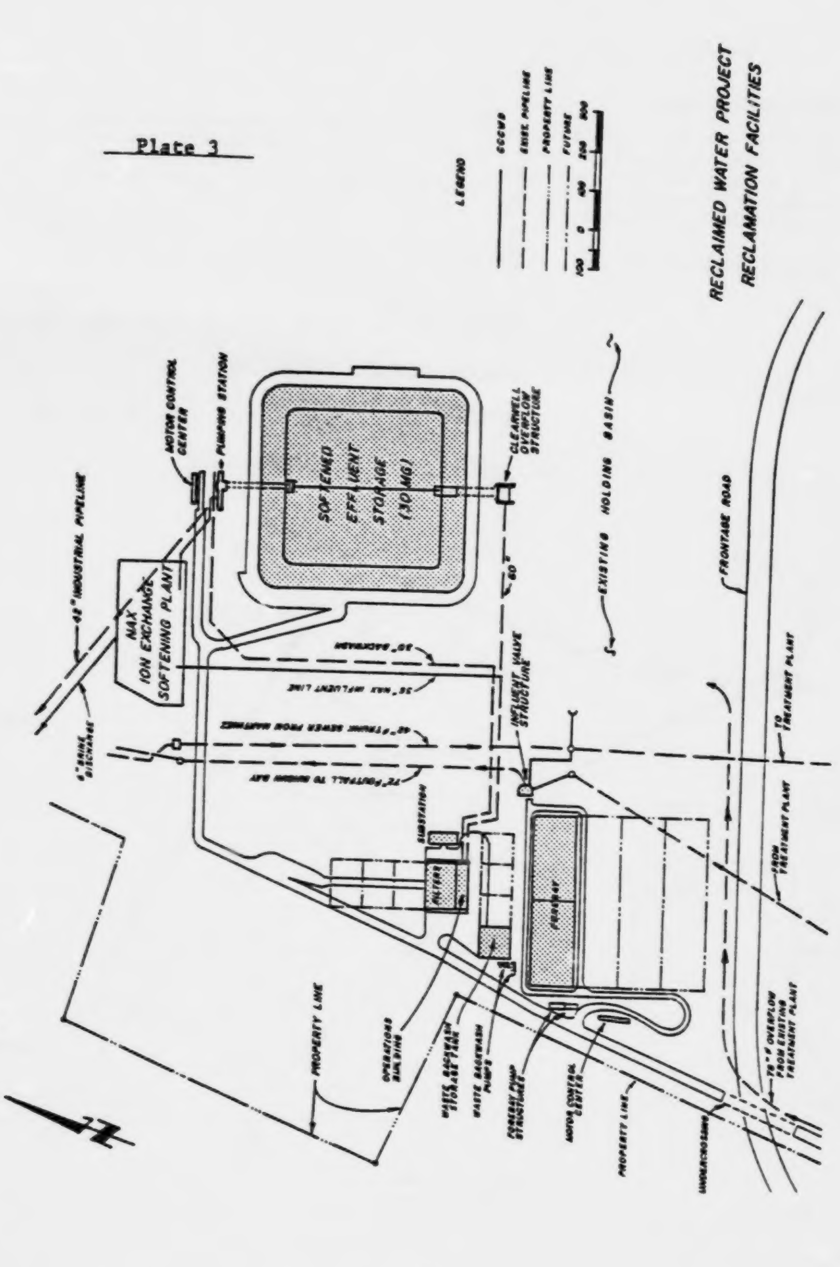
The CCCWD project facilities consist of a sodium ion exchange softening plant (NaX) of 15 MGD capacity (designed to expand to 30 MGD), two 3-MG storage tanks and appurtenances (with provision for a third tank), conversion of various pipelines to reclaimed water use and construction of new pipelines and pump stations.

Project Contractors:	1.	Distribution System Pipelines M. G. M. Construction Company, Concord, Ca.	$1.150,000
	2.	Storage Tanks Chicago Bridge & Iron Co., San Francisco, Ca.	$ 630,000
	3.	Ion Exchange Softening Plant	
	a.	Equipment Contractor: I. W. T. Co., Rockford, Ill.	$ 930,000
	b.	Support Facilities Contractor: Dalzell Corporation, Oakland, Ca.	$1,320,000



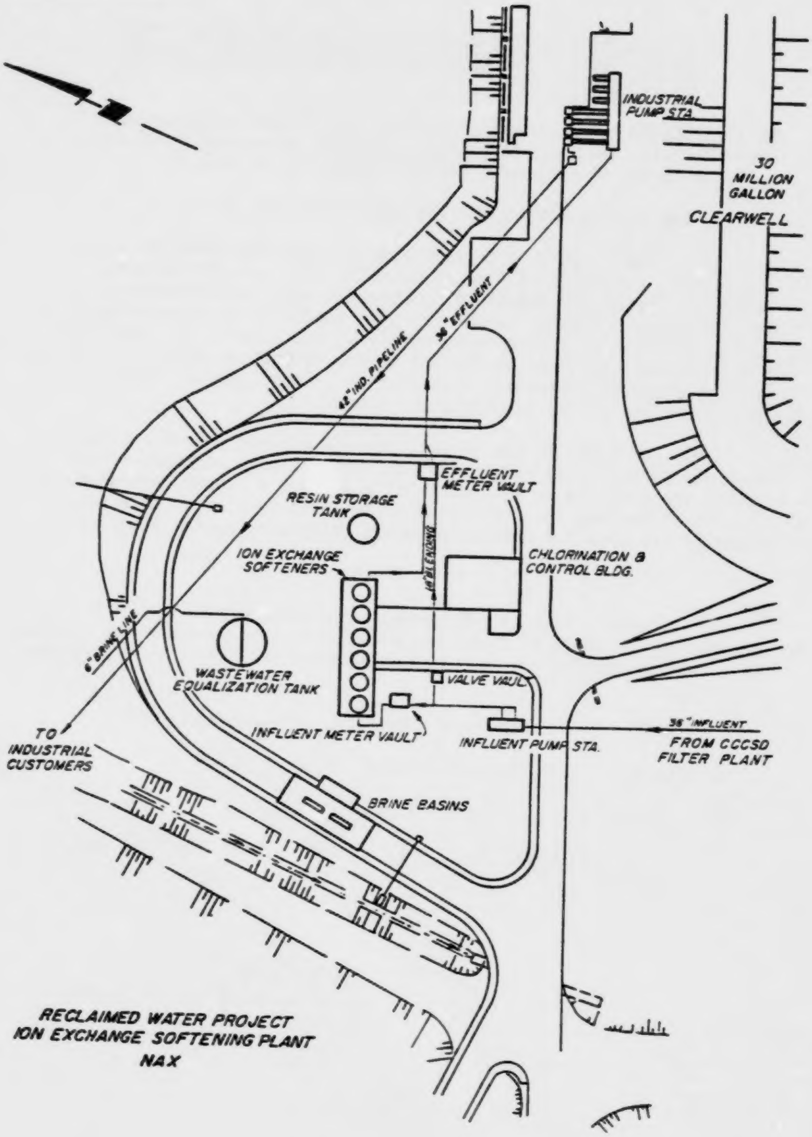
LOCATION MAP

Plate 3



RECLAIMED WATER PROJECT
RECLAMATION FACILITIES

Plate 4



RECLAIMED WATER PROJECT
ION EXCHANGE SOFTENING PLANT
NAX

Plate 5

RESOLUTION NO. 72 - 58

A RESOLUTION OF THE BOARD OF DIRECTORS OF CONTRA COSTA WATER DISTRICT ADOPTING A REGULATION GOVERNING SERVICE OF RECLAIMED WATER.

BE IT RESOLVED by the Board of Directors of Contra Costa County Water District that the following regulation governing service of reclaimed water is adopted effective forthwith, to read:

USE OF RECLAIMED WATER FOR INDUSTRIAL COOLING

(a) The District will from time to time determine the points, quantities, and rates of flow at which it will deliver reclaimed water for use by its industrial customers. Said determinations shall be made solely by the District on the basis of the availability to the District of a dependable supply of reclaimed water, the feasibility of the distribution thereof to the respective point of delivery, and the water requirements, distribution system, and cooling equipment locations of the industrial customer.

(b) When and to the extent that the District makes available a supply of reclaimed water at a point of delivery adjacent to or within the property of an industrial customer, no water furnished by the District other than reclaimed water shall be used by such industrial customer for cooling purposes designated by the District.

****

I certify that the foregoing resolution was duly and regularly adopted by the Board of Directors of Contra Costa County Water District at a regular meeting thereof held on December 20, 1972, by the following vote.

AYES:	Directors Randall, Weidner and Lasell.
NOES:	Director Stitt
ABSENT:	Director Siino

IN WITNESS WHEREOF, I hereunto set my hand this 20th day of December, 1972.

John L. Potts
Secretary to Board of Directors
of Contra Costa County Water
District

AWT EVALUATION IN TWO SELECTED INDUSTRIES

Richard A. Osantowski, Project Engineer
Anthony Geinopolos, Assistant Director
Rexnord, Inc.
Environmental Research Center
5103 W. Beloit Road
Milwaukee, WI 53214

INTRODUCTION

This project was initiated to provide an evaluation of the effectiveness of existing treatment technology in renovating process waters to meet various non-potable reuse applications. The project was funded by the Office of Water Research and Technology under Contract No. 14-34-0001-7805. Wastewater reuse is oriented toward supplementing existing water supply sources and conserving limited national water resources. Specifically, the purpose of this project was to determine the most feasible and economical approach to treat and reuse the wastewaters now generated from selected high water usage industries. The wastewaters tested were effluents from operating industrial treatment systems that meet 1977 Effluent Guidelines for Best Practical Control Technology Currently Available (BPCTCA).

The project objective was to conduct an in-depth pilot plant program to investigate the applicability of advanced treatment methods (ion exchange, reverse osmosis, and electrodialysis) for renovating BPCTCA industrial wastewaters. The study was performed using mobile treatment facilities containing pilot scale desalting and pretreatment equipment.

The project objective was achieved through the performance of a program consisting of the three phases outlined below:

Phase I - Design and Fabrication of a Mobile Treatment Facility Housing Ion Exchange, Reverse Osmosis, and Electrodialysis Pilot Scale Equipment.

Phase II - Bench Scale Investigations of the Selected Industrial Plant's Treated Effluent.

Phase III - Operation and Evaluation of the Advanced Waste Treatment Pilot Plant Investigations at the Selected Industrial Sites.

The purpose of the first phase was to provide a mobile pilot testing facility to evaluate the ion exchange, reverse osmosis, and electrodialysis treatment technologies. The portable treatment system developed included the technology needed to remove the residual contaminants in the industrial BPCTCA wastewaters to the extent that these wastewaters were upgraded to non-potable reuse quality. A schematic representation of this desalting mobile pilot van is shown in Figure 1. This van was used in conjunction with the Envirex Advanced Waste Treatment (AWT) vehicle (Figure 2). The AWT van contained the flocculation-clarification, filtration, and carbon adsorption equipment that was used for pretreating the waste prior to the desalting technologies.

The purpose of the bench-scale work was to provide information concerning the advanced waste treatment method to be studied in the Phase III pilot plant investigation (design and operation). Of particular interest were such items as the pretreatment requirements, magnitude of operating variables, expected magnitude of treatment efficiency and effluent quality, selection of equipment and media, and pilot plant system design.

During the pilot testing phase, the movable waste treatment systems were field operated at the chosen industrial sites to obtain an evaluation of the applicability and feasibility of the selected treatment technology to the treatment of the respective wastewater. The study was conducted on a pilot plant scale of sufficient size to permit the development of performance and basic design criteria which were used for scale-up to full size equipment. The period of time spent at each site was 10 weeks.

The advanced waste treatment methods, both singularly and in combination, which were investigated on a pilot basis in Phase III included those presented below:

1. CT + DMF + RO
2. CT + DMF + AC + IE
3. CT + DMF + AC + ED
4. DMF

Key

CT - Chemical Treatment
DMF - Dual Media Filtration
RO - Reverse Osmosis
AC - Activated Carbon
IE - Ion Exchange
ED - Electrodialysis

For each treatment train investigated, samples and operational data were obtained for later use in assessing, evaluating, appraising and comparing the adequacy of the individual advanced waste treatment methods.

Evaluation and comparison of the data were performed using the criteria: (1) process and/or treatment train performance, (2) capital and operating costs and (3) space requirements.

Three industrial sites were selected. The industries chosen were high water users and may be identified by the products manufactured, namely, (1) paper products, (2) food products and (3) organic chemical products. This paper reports on the findings from two of these sites.

DESCRIPTION OF PILOT EQUIPMENT

The mobile treatment equipment used during the study contained an extensive system of pressure and flow gauges, pH and flow recorders, and automatic control loops for pH, flow control, and system backwash.

The clarification system contained a 2,000 gallon (7,570 ℓ) flocculator-clarifier equipped with a five pump chemical addition system. The dual media filter was a 20 inch (50.8 cm) diameter unit equipped with an automatic backwash system including adjustable air scour. The four carbon adsorption columns are 10 inches (25.4 cm) in diameter and can be operated upflow, downflow, in series or in parallel. The carbon columns are also equipped with backwash capability including air scour.

The ion exchange system consisted of cation and anion exchange units. Each unit can hold 2 ft^3 (0.056 m^3) of resin. The cation discharge is equipped with an in-line pH meter, while the anion discharge contains an in-line conductivity meter. A solenoid valve stops flow on high pH or conductivity. The reverse osmosis unit consists of a pressure vessel housing 3 spiral wound membranes. The system is equipped with a brine recycle loop which can be used to achieve a 75% recovery. The RO system is protected by high and low pressure switches and an in-line cartridge filter (5 μ).

The electrodialysis unit contains 4 hydraulic stages and 2 electrical stages. There are 86 cell pairs total. The system is equipped with a timer operated polarity reversal which containually flushes the electrodes during operation.

PAPER PRODUCTS RESEARCH SITE

General

A deinking mill producing 165 metric tons (150 tons) of product per day was selected as the paper products research site for the advanced wastewater treatment pilot-scale study. The main products of the mill are paper towels, napkins, and other absorbent tissues.

Water used in the mill's paper manufacturing process is taken from the city well water system and a local river. A percentage of the paper mill's water requirements are also satisfied by the recycling of primary effluent from their wastewater treatment system. A breakdown of current water usage in the mill's manufacturing process is presented in Table 1. As shown in the table, city water is used to supply the boiler, suction rolls and wire showers. River water is used to supply the felt showers and vacuum pump seals. The remainder of the mill's process operation is supplied with recycled primary effluent. Approximately 3 MGD (11,355 m^3/day) of primary effluent is recycled back to the mill.

Wastewater Treatment System

The wastewater treatment system consists of primary and secondary treatment. The primary treatment system, completed in 1975, removes a significant portion of the fiber and clay present in the waste process waters. Solids removal is enhanced by chemical flocculation with the addition of alum and polymer before clarification. The secondary treatment system, completed in 1977, consists of an aeration basin followed by a final clarifier. The effluent from the final clarifier, 3-4 MGD (11,355-15,140 m^3/day), is discharged to the river.

Results of Testing

Performance. During the pilot program, chemical clarification, dual media filtration, and activated carbon were investigated as pretreatment methods prior to the desalting technologies. The data obtained during the study indicated that the pilot scale clarifier was capable of reducing the suspended solids by 57% and the BOD_5 by almost 75% The dual media filter further reduced the clarifier effluent suspended solids from 27 mg/l to 7 mg/l. Activated carbon was successful in removing approximately 70% of the incoming TOC and 82% of the feed COD. The results of the pretreatment investigation are presented in Table 2.

Three processes, namely ion exchange, reverse osmosis and electrodialysis were investigated as possible methods of demineralizing the wastewater for potential reuse by the paper mill. With proper pretreatment, each of these processes was capable of producing a water quality similar to the potable water supply. A comparison of the three effluent qualities (Table 3) indicates that for all of the parameters analyzed, the product water concentrations are nearly equal.

Costs. Data obtained from the pilot study were submitted to vendors for scale-up to full size equipment. Design criteria were developed for flows of 1 MGD (3,785 m^3/day), 4 MGD (15,140 m^3/day), and 30 MGD (113,500 m^3/day). The cost summaries for a 4 MGD (15,140 m^3/day) design are presented in Table 4. Operating costs for an ion exchange system are estimated at $3.206/1,000 gal. ($3,206/3,785 ℓ) compared to $0.997/1,000 gal. ($0.997/3,785 ℓ) for reverse osmosis and $1.348/1,000 gal. ($1.348/3,785 ℓ) for electrodialysis. In regard to capital costs, the reverse osmosis system is lower than ion exchange or electrodialysis.

Space Requirements. The space requirements for a 4 MGD (15,140 m^3/day) design for an ion exchange, reverse osmosis, and electrodialysis system are shown below.

Ion Exchange	0.60 acres (2,467 m^2)
Reverse Osmosis	0.42 acres (1,721 m^2)
Electrodialysis	0.57 acres (2,319 m^2)

The space requirements are for the complete system including pretreatment. Reverse osmosis has a slightly lower areal requirement than ion exchange or electrodialysis.

Reuse Evaluation

Water quality guidelines exist for each of the paper mill's reuse possibilities listed previously in Table 1. Knowing the quality of effluent available from each of the processes investigated, it is possible to match and blend the effluents to meet the reuse requirement. This has been done in Table 5. The table indicates the reuse source, flow required from various advanced technologies, blended water percentage, and the cost to provide reusable water. Reverse osmosis has been assumed as the demineralization process. The costs shown do not include the cost of a distribution or storage system. Cost savings expected by reduced potable water consumption [$0.17/1,000 gal. ($0.17/3,785 ℓ)] have not been taken into account. The blended water will meet the reuse quality requirements from a standpoint of plugging (suspended solids), corrosion (pH, dissolved solids), scale (calcium, sulfate), foaming (dissolved solids buildup), slime (organics), and color.

FOOD AND KINDRED PRODUCTS RESEARCH SITE

General

A large meat processing firm was selected as the second research site. The plant is both a slaughtering and manufacturing facility. The manufacturing division produces bacon, a variety of large and small sausages, hams, and other meat products. A packaging division, a lard and inedible rendering plant, and a laboratory processing raw materials for pharmaceuticals are also located at the site.

Wastewater Treatment System

Grease water from the kill floor, cutting floor, and processing plant and manure water from the stockyards, slaughtering, and inedible rendering departments are combined, treated, and discharged to an interceptor sewer of the local sewage district. A production-day wastewater flow of 4.0 MGD (15,140 m^3/day) undergoes primary and secondary treatment before being discharged.

Water Supply

The firm's water supply is taken from wells on the property (80%) and from purchased city water (20%). Potable water is required in all process, washing, and cleanup operations and 82 °C (180 °F) water is used for viscera pan washing and other applications specified by the United States Department of Agriculture (USDA).

Results of Testing

The food products research study was conducted from June to September, 1978 using secondary effluent as a source of feed. The technologies investigated were similar to those evaluated at the paper products site. Pretreatment removal data are shown below.

	Influent	Effluent	% Removal
Chemical Treatment			
BOD, mg/l	118	47	60
SS, mg/l	112	33	71
Filtration			
SS, mg/l	33	11	67
Activated Carbon			
TOC, mg/l	26	10	62

The data indicate that chemical treatment and filtration were effective in removing suspended solids. Organics removal was also observed through the clarifier as well as the activated carbon.

With regard to demineralization, all three of the desalting processes investigated were capable of reducing the influent dissolved solids (~2,000 mg/l) by about 90%.

Potential Reuse

A rather extensive recycling and reuse program is already in effect within the plant. All recycle and reuse plans involving contact with any product or by-product must be approved by the USDA. The potential exists for using greater quantities of high quality water as non-contact cooling or boiler makeup waters. Shown below are several potential uses of high quality effluent and the reuse quantities required.

Use	Volume
Boiler feedwater makeup	180,000 gpd (681,300 ℓ/day)
Power plant cooling tower makeup	100,000 gpd (378,500 ℓ/day) (summer) 40,000 gpd (151,400 ℓ/day) (winter)
Office air conditioning cooling tower makeup	30,000 gpd (113,550 ℓ/day) (summer)
Inedible vapor controller makeup	25,000 gpd (94,625 ℓ/day)
Various other non-contact cooling water makeup	500,000 gpd (1,892,500 ℓ/day)

The food products plant can potentially reuse 0.835 MGD (3,160 m^3/day) of secondary effluent in the plant. Work is currently being finalized on matching the effluent qualities available to the quality of water required by the individual reuse operations.

ACKNOWLEDGEMENTS

Rexnord Inc. acknowledges the cooperation and support of the Office of Water Research and Technology, U.S. Department of Interior. The assistance given by Allen Ford, Project Officer, and Robert Madancy, Chief, Office of Water Research and Technology was received with much appreciation.

TABLE 1. PAPER PRODUCTS COMPANY - CURRENT WATER PRACTICE

Process	Current usage			Quantity m^3/day (MGD)	Comments
	City water	River water	Recycled effluent		
Pulpers			✓	2,839 (0.8)	Higher quality water preferred
Felt showers			✓	946 (0.3)	Higher quality water preferred
Felt showers		✓		5,678 (1.5)	Reuse possibility
Vacuum pump seals		✓		189 (0.05)	Reuse possibility
Lubrication water			✓	2,195 (0.6)	Higher quality water preferred
Gland water seal			✓	3,785 (1.0)	Higher quality water preferred
Bearing cooling			✓	114 (0.05)	Higher quality water preferred
Hoses			✓	114 (0.05)	Higher quality water preferred
Boiler feed	✓			568 (0.15)	Reuse possibility
Suction rolls } Wire showers }	✓			1,893 (0.5)	Reuse possibility

(Per the Plant Engineer)

(PRELIMINARY)

TABLE 2. PAPER PRODUCTS PRETREATMENT REMOVAL DATA

	Influent	Effluent	% Removal
Chemical Treatment			
BOD, mg/l	23	6	74
Suspended solids, mg/l	57	27	57
Dual Media Filter			
Suspended solids, mg/l	27	7	74
Activated Carbon			
COD, mg/l	79	14	82
TOC, mg/l	26	8	69

(PRELIMINARY)

TABLE 3. PAPER PRODUCTS DEMINERALIZATION REMOVAL DATA

	Influent	Effluent	% Removal
TDS, mg/l			
Ion exchange	1,133	88	92
Reverse osmosis	1,163	55	95
Electrodialysis	1,150	135	88
Sodium, mg/l			
Ion exchange	294	9	97
Reverse osmosis	296	6.2	98
Electrodialysis	300	23	92
Chloride, mg/l			
Ion exchange	153	14	91
Reverse osmosis	146	10.5	93
Electrodialysis	178	17	90

(PRELIMINARY)

TABLE 4. TREATMENT TRAIN COST SUMMARY
4 MGD (15,140 m^3/day) DESIGN

Capital Costs

Process	Ion Exchange	Reverse Osmosis	Electrodialysis
Clarification	$ 367,200	$ 367,200	$ 367,200
Filtration	270,700	270,700	270,700
Activated Carbon	2,650,000	-	2,650,000
Ion Exchange	1,548,000	-	-
Reverse Osmosis	-	2,415,000	-
Electrodialysis	-	-	3,154,800
TOTAL	$4,835,900	$3,052,900	$6,442,700

Operating Costs $/1,000 gal.[1] ($/3,785 ℓ)

Process	Ion Exchange	Reverse Osmosis	Electrodialysis
Clarification	$0.160	$0.160	$0.160
Filtration	0.057	0.057	0.057
Activated Carbon	0.550	-	0.550
Ion Exchange	2.439	-	-
Reverse Osmosis	-	0.780	-
Electrodialysis	-	-	0.581
TOTAL	$3.206	$0.997	$1.348

[1] Product Water

(PRELIMINARY)

TABLE 5. TYPE AND QUANTITY OF REUSE WATER REQUIRED FOR VARIOUS MILL OPERATIONS AND ASSOCIATED COSTS

	Proposed Reuse Volume Required Per Day							
Reuse Source	Mill Flow MGD	Secondary Effluent MGD	Chemically Treated Effluent MGD	Dual Media Filter Effluent MGD	Reverse Osmosis Product Water MGD	Reused Water Source	Cost To Provide Reusable Water[1,2,3] $/1,000 gal. ($/3785 ℓ)	Paper Mill Water Cost $/1,000 gal. ($/3785 ℓ)
Pulper	0.80	0.93	0.52	0.53	0.40	50% Sec. Eff. & 50% R.O. Product	0.499	0.17
Felt Showers	1.80	2.10	1.2	1.2	0.9	50% Sec. Eff. & 50% R.O. Product	0.499	
Vacuum Pump Seals	0.05	0.058	0.033	0.033	0.025	50% Sec. Eff. & 50% R.O. Product	0.499	
Gland Water Seals	1.00	1.20	1.20	1.20	0.60	40% DMF Eff. & 60% R.O. Product	0.685	
Bearing Cooling	0.05	0.06	0.06	0.06	0.03	40% DMF Eff. & 60% R.O. Product	0.685	
Hoses	0.05	0.058	0.033	0.033	0.025	50% Sec. Eff. & 50% R.O. Product	0.499	
Suction Rolls/ Wire Showers	0.50	0.58	0.33	0.33	0.25	50% Sec. Eff. & 50% R.O. Product	0.499	
Boiler Feed	0.15	0.20	0.20	0.20	0.15	100% R.O. Product	0.997	
TOTAL	5.75	5.19	3.59	3.59	2.38	(3.17 MGD Required Feed to R.O.)		

NOTE: MGD x 3785 = m^3/day
1. Does not include cost of operating existing secondary treatment plant
2. Assuming design flow of (4 MGD) 15,140 m^3/day
3. Cost is independent of equipment required for blending effluents

(PRELIMINARY)

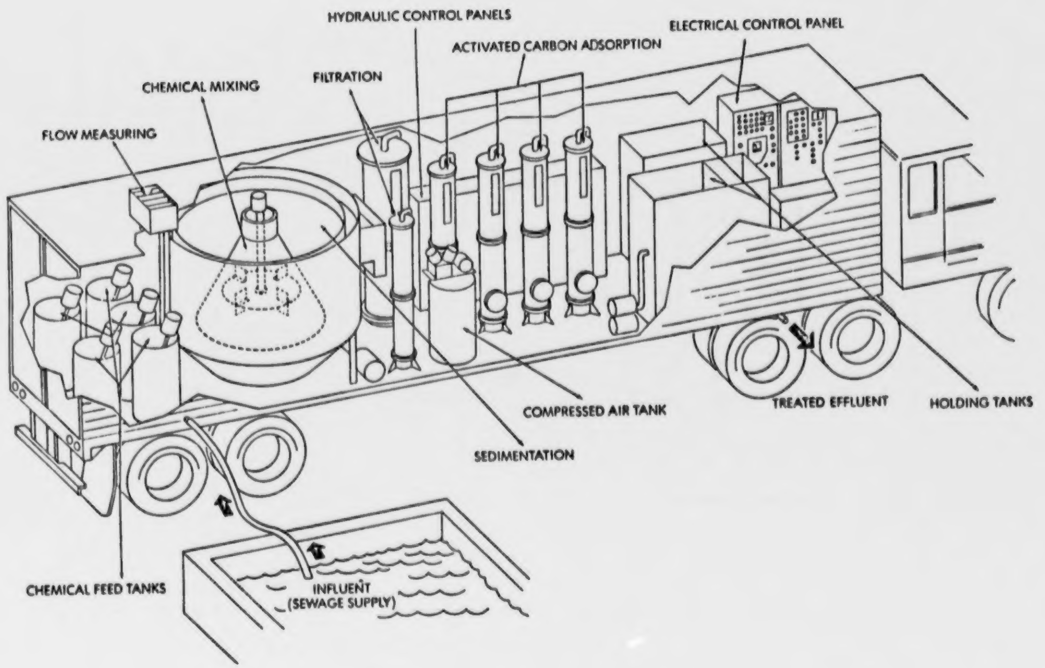
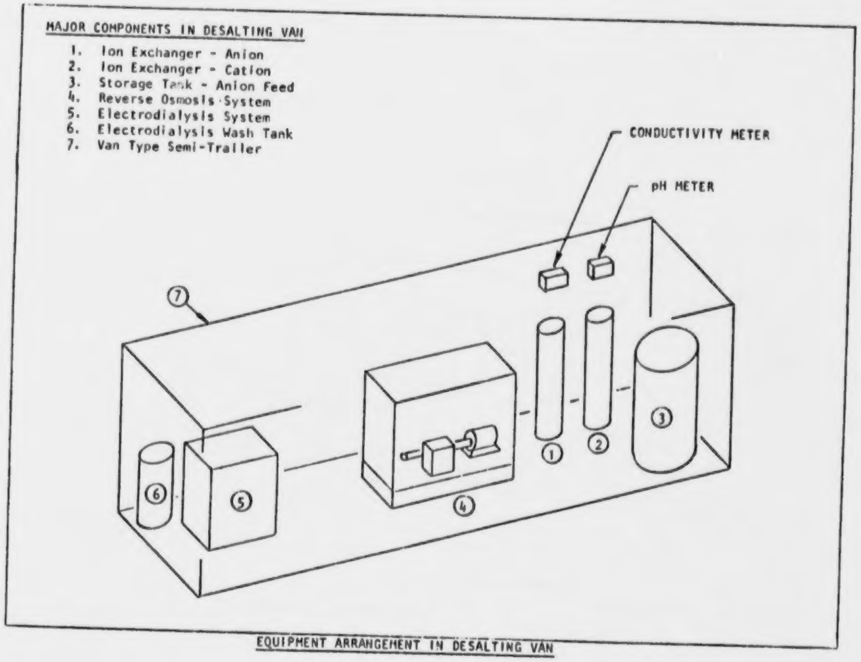


Figure 1. Envirex advanced waste treatment mobile unit.


MAJOR COMPONENTS IN DESALTING VAN
1. Ion Exchanger - Anion
2. Ion Exchanger - Cation
3. Storage Tank - Anion Feed
4. Reverse Osmosis System
5. Electrodialysis System
6. Electrodialysis Wash Tank
7. Van Type Semi-Trailer
CONDUCTIVITY METER
pH METER
⑦
③
②
①
④
⑤
⑥

EQUIPMENT ARRANGEMENT IN DESALTING VAN

Figure 2. Desalting mobile treatment van.

TOTAL WATER REUSE - CAN INDUSTRY AFFORD IT?

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There are many reasons why industry, municipalities and regulatory authorities are concerned about the reuse of water. Probably the two foremost and immediate concerns are environmental protection regulation and conservation of clean water.

In order to meet the ever increasing demands of the regulatory authorities, industry must continually reduce contaminants in its discharges. A contaminant or pollutant is defined as any substance which is not contained in the natural water. It is difficult to define what exactly is the natural background water quality. Is it the present quality of the raw water taken in by an industrial plant from a river? or is it the quality of the river water far enough upstream so that it is not affected by any unnatural contamination? This dilemma makes assessing the problem and reaching a solution difficult.

Basic to the discussion of water reuse are three terms commonly used throughout this paper.

Abstraction - Water brought into a facility for use. This water may be from lakes, rivers, wells, or from the domestic water supply. This may also, in some cases, include water that is brought in on the raw material.

Discharge - Water that, after use, is discharged from the facility into a receiving water body or sewer. This would include water that is used on a once-through basis, blowdowns from recirculating systems and dumps, bleedoffs, etc.

Consumption - Water that is consumed in the production process, evaporated in cooling towers or sludge driers and water consumed in the product.

If a proper water balance is made of a typical facility it will be seen that:

$$\text{Abstraction} = \text{Discharge} + \text{Consumption}$$

An industry which is a large water consumer, with a wastewater treatment system operated on a once through basis, will most likely have difficulties in meeting the regulatory standards. The task of cleaning such large volumes to the required degree, even though the effluents may not be very contaminated, is monumental. The size of the operation needed, the space it will occupy, the costs it consequently will entail, all militate against such a project.

Moreover, after treatment, the water to be discharged often is of a superior quality to that of the raw water supply. The question then arises, "Why not recycle the treated water, and discharge only a small blowdown?" Basically, in order to meet the BAT (Best Available Technology Economically Achievable) requirements, this is exactly what must be accomplished.

Reuse of water reduces to manageable levels the volume of final effluent to be treated. It also reduces the amount of water to be abstracted. These are desired consequences.

For water being discharged after treatment, there are no present federal thermal requirements which have to be met. In many cases, this water can be discharged without cooling, provided it meets State, local, or regional standards. However, if the water is to be recirculated, cooling is usually required, with its associated increase in consumptive water loss.

A rule of thumb is that for every 5.6°C (10°F) of cooling, one percent of an atmospheric cooling tower's flow is lost to evaporation and between 0.1 to 0.3 percent to windage. In addition, in some cases, the blowdown must be treated for contaminants picked up in the process, and/or for chemicals added to the recirculating water for conditioning purposes.

Energy requirements also will increase due to the requirements for more pumping capacity and for operation of cooling tower fans. Also, additional chemicals will be required for water conditioning. This will increase energy usage for production of these chemicals and, in general, increase operating costs for the treatment system.

A reuse system, therefore, must be carefully planned, based on detailed knowledge of the quality of water needed for each application and the contaminants which are added to the water in each process. Treatment of each effluent must be tailored to its contaminants and its next use. Certain processes do not require very clean water. In such cases, effluent from another process may be applied directly. If a series of such applications is made, the water becoming more contaminated with each step, a cascade effect takes place. This requires treatment of a highly polluted water only once before returning the water back to the source.

This is in distinction to recycling, where the water is more or less in a closed loop, continuously applied to one production process. Such a cycle may include a treatment system to remove contamination from the process water to a degree suitable for reuse.

However, particularly in the recycling of indirect cooling water, (water which is not in direct contact with that which it is cooling), the only treatment necessary is lowering the temperature of the water, controlling corrosion by chemical addition, and controlling dissolved solids buildup. If a cooling tower is used, there will be water loss to evaporation and therefore an increase in dissolved solids. In addition, the water may pick up contaminants such as particulate matter from its contact with the air. In such cases, a small blowdown is necessary, as well as makeup to replace the volume lost to evaporation, drift, and the blowdown. If a closed cooling system is used, in which cooling water generally does not come in contact with air, there is no water loss and minimal makeup is required.

To increase water conservation within a plant, the blowdown from one recycling system can be used as makeup for another recycle system. This is another form of cascading, where higher quality water is used successively in systems of lower quality.

A goal of PL-92-500 is that zero discharge of pollutants be achieved by 1985. This would require almost "total recycle" by virtually eliminating the discharge of all effluent from the plant. Technically, this can be achieved.

Hydrotechnic has recently concluded a study on such water reuse for the steel industry. The study took into account two stages: BAT, which is mandated for 1984, and total recycle. The steel industry is a particularly interesting one to study because of the wide variety of processes involved and the pollutants produced. The choices in treatment for the various effluents and modes of operation make this one of the most complex problems in water treatment. Added to this is the fact that there is no typical integrated steel mill. Each one is different and must be considered individually.

An integrated steel plant uses as much water as some of our larger cities. The larger plants, with 10 million tons annual production, approach a billion gallons per day. Some of the steel plants have practiced internal or external water reuse for decades. Bethlehem Steel's Sparrows Point, Maryland, plant uses Baltimore City's backbay sewage treatment plant effluent as its industrial service water supply. Kaiser Steel's, Fontana, California, plant uses an intensive, internal cascade system of reuse. These plants, however, are not typical of the industry.

The treatment of steel mill wastewater utilizes physical, chemical and biological treatment systems. In general, the removal of organics, cyanide and ammonia can be achieved by using staged biological treatment or physical chemical techniques depending on the source. Most suspended solids are eliminated by gravity, with the finer particles removed by filtration. Oil and grease also are separated with the aid of gravity; when necessary, chemical de-emulsifiers or coagulants are employed. Finally, dissolved solids are extracted by reverse osmosis.

Reverse osmosis and some of the alternative processes available leave concentrated effluents. For zero discharge of water, it is necessary to evaporate the water from these. The remaining solids must be disposed of by an environmentally acceptable method.

For the steel industry in the United States, achievement of the BAT quality level would require an increase in power generation of about 260 MW over that presently required to achieve BPT (Best Practical Technology) levels. For total recycle or zero discharge of water, however, an additional 923 MW would be needed. The generation of this power may cause additional environmental concern.

One of the ironies of the requirement to achieve zero discharge is that the amelioration of water quality levels in itself leads to an increased consumptive water loss. The amount of water lost to achieve BAT qualities in the steel industry would be 38.5×10^6 m^3/yr. Total recycle, or zero discharge, would entail a water loss of 364×10^6 m^3/yr. On the other hand, there would be a decrease in water abstraction, by 28.6% for BAT and by 91.3% for total recycling. However, for BAT, less of the water abstracted would be returned to the natural water system and for total recycling, no water would be returned.

Naturally, the work required for these improvements and for the maintenance of the new treatment facilities would increase the cost of the product, steel. We have estimated that the requirements of meeting BAT standards would increase the price of steel by $2.87 (1978 dollars)/ton (metric) of steel. Total recycle should cause a rise of $18.49/metric ton over current prices. Based on present national production the relative annual increased costs for BAT and zero discharge would be $400 million and $2.7 billion respectively. The cost of achieving zero discharge of pollutants would be between the cost of BAT and the cost of the ultimate no discharge of any water.

In estimating these costs, allowance was made for unexpected increases in the various contributing factors. However, as has been shown by recent occurrences in Iran, which led to an unexpected and rather hefty rise in the price of fuel, world events can cause a marked increase in these costs.

For the steel industry, while recycle may indeed lead to the elimination of pollutants from the national environment, the additional costs may make domestic steel less competitive with that produced abroad. What may, in fact, occur, is that pollution will be exported to countries who are willing to accept some degree of environmental deterioration.

Moreover, while total recycling results in no waters being discharged to rivers and lakes, it does not totally confine the water being used. Much of the water consumed is lost to the atmosphere. A good portion of this could be recovered for reuse. This would necessitate condensing the water out of the air discharged from the mill. But each attempt to further constrict the water loss leads to an almost exponential increase in cost. The line has to be drawn somewhere. There is a limit to how much can be done within reason, presently.

A particular problem of this increased treatment is disposal of the solid wastes produced. Suitable disposal sites must be found and the wastes hauled there. Those wastes which are insoluble in water will remain at the dump site. But what is to be done with water soluble wastes? If left in a dump, they eventually will be leached out, back into the environment. Alternative uses may be found for some of these materials, but they may not be feasible. Perhaps, what is needed, ultimately, are modified processes of manufacture, which are designed specifically to be less polluting. An example would be the direct reduction of iron ore followed by its conversion to steel in an electric arc furnace, thereby eliminating the highly contaminated coke plant and blast furnace discharges.

In contradistinction to the steel industry is the power industry which has one predominant use for the water -- cooling. In areas where water is plentiful, some power plants have been operating cooling systems on a once through basis.

These will have to be converted to recycle cooling systems. Many plants already are recycling their cooling water using cooling towers. Smaller, older facilities can generate about 20 kJ per liter of cooling water used. Newer, larger facilities, which can operate at a larger water temperature differential, can generate about 50 kJ/l. Obviously, these larger facilities are more frugal in their use of water. In time, as older plants are phased out, there will be a natural increase in water efficiency in the power industry.

With the recycling of cooling tower water, there will be a build-up of solids, both dissolved and suspended, carried by the water. This will necessitate a blowdown which must be treated. The use of larger generators will lower the cost of water treatment which would be required.

In going to a total recycle system, where no liquid can be discharged, conversion to a dry, closed air cooling system is preferable. While a dry cooling system costs from two to four times as much as a wet cooling system, and is twice as expensive to operate, there is no blowdown to treat. When blowdown is added to the costs of a wet system, over a period of years, dry cooling becomes more economical. For a cooling system using 10,000 gpm and operating at a temperature differential of 15°F, we estimate that the total cumulative cost of a wet system will overtake that of a dry system in less than three years. Over a period of ten years, the use of a dry system of this size should result in a saving of about $1,000,000.

What makes the wet system uneconomical in this situation is the restriction of total recycle with no discharge. If controlled and treated blowdown is permitted, the wet system is competitive with the dry cooling system.

For certain new plants and new production facilities, it is technically possible and economically feasible to incorporate tightly bottled-up water facilities and arrive at zero discharge. Advances in new technologies are allowing more of the newer plants to approach closer to the concept of total recycle and reuse. The difficulty with total reuse is applying it to old existing plants. Retrofitting recycle systems into existing plants is technically possible but total recycle of water for old production facilities is usually considerably more expensive.

In conclusion, water reuse is desirable, necessary, and in many cases the economical way for industry to meet the ever more stringent environmental control regulations, and to conserve the increasing scarcity of clean water. However, total water reuse is impractical, particularly for the industries which utilize great volumes of water in their operations. Not only is the cost excessive in relation to benefit, but increased energy is required, there is greater water loss, and increased power requirements may cause detrimental environmental effects. Similarly, increased evaporation of water may have adverse meteorologic and hydrologic effects.

Therefore, before any system approaching total reuse of water is implemented by an industry, proper studies, planning and engineering must be completed by firms specialized and experienced in the industries in question to arrive at proper designs of efficient water reuse systems. Without the necessary knowledge and experience, the systems installed can become costly white elephants which are only partially successful.

INDUSTRIAL REUSE OF WASTEWATER: COST ANALYSIS AND PRICING STRATEGIES

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INTRODUCTION

In an industrial context, cooling towers have been the primary point of application for reclaimed municipal wastewater. According to a 1975 EPA survey[1], 154 mgd out of a total 156 mgd of industrial reuse of reclaimed municipal wastewater occurred in cooling systems. This is expected since cooling represents the largest single water-using process in industry, and since relatively low quality water can serve the cooling needs. In spite of the recognized potential for use of reclaimed wastewater in cooling systems, actual application has not been widespread, even in water-short southern California. Municipal wastewater reuse for cooling is still viewed by water purveyors and users alike as a complicated subject fraught with unique problems.

This paper discusses efforts at James M. Montgomery, Consulting Engineers, Inc., to computerize the water quality and water quantity models necessary to analyze the potential for successful industrial use of reclaimed wastewater. This reuse market, for a variety of purposes such as groundwater recharge, seawater intrusion barriers, agricultural and landscape irrigation, and industrial cooling, is enormous. For the Los Angeles and Orange County areas alone, with a total basin use of 2 mil acre-ft/year, nearly 25 percent or 500,000 acre-ft/year of reclaimed wastewater could be applied to the above purposes. Of that amount, at least 100,000 acre-ft/year could be used in cooling towers alone[2].

This figure is indicative of the tremendous water reuse potential available in the Los Angeles/Orange County areas which have a combined population of 8-1/2 million.

For the purposes of the Los Angeles/Orange County Water Reuse Study, JMM has divided the two-county area into ten service areas, generally broken down by water quality needs of potential users within each area (Fig. 1). Already existing in the area are nine reclamation facilities providing tertiary treatment (activated sludge and filtration) for 127,000 acre-ft/year. Planned expansions plus two proposed new plants will bring capacity to 1/4 million acre-ft/year. In addition, Los Angeles City's Hyperion Plant provides secondary treatment to 100 mgd and primary to another 200 mgd, and Los Angeles County Sanitation District's Joint Water Pollution Control Plant provides primary treatment to approximately 350 mgd. The potential reuse of this water supply plus other motivations have combined to make the Reuse Study an extremely timely undertaking.

As the recent drought illustrated, additional water supplies are needed now. This need will increase in the 1980's because of a cut-back in the California entitlement to Colorado River water caused by the startup of the Central Arizona project and by potential restrictions in the amount of water available from northern California. The incremental cost of developing new freshwater resources together with their delivery systems has increased rapidly, as the most efficient sources are already developed. For example, the capital cost of improving and enlarging some existing water sources runs $75/acre-ft, whereas the cost to develop new reservoirs ranges between $100 and $200/acre-ft.

In the past few years the standard treatment requirements for wastewater discharge have become as stringent as the treatment requirements governing reuse. As a result, the region's treatment plants are rapidly being upgraded to reclamation plant status. State and federal water quality legislation has brought about an unprecedented construction of advanced wastewater treatment. In addition to the existing 127,500 acre-ft of reclamation facilities currently on line, an additional 80,000 acre-ft/year is planned for construction for the mid-1980's. The public's investment in this legally-mandated treatment now stands at more than $50,000,000 and operating expenses exceed $5 million each year. Surely better uses can be made for this reclaimed water than continued discharge to the ocean.

Finally, reuse provides water resource benefits while conserving fuel and energy. For example, in April 1983, the existing favorable long-term pumping contract for transporting northern California water to southern California will expire, and the anticipated new costs for pumping an acre-ft will increase tenfold to $100/acre-ft. Reuse of the wastewater at the inland service districts shown in Figure 1 will reduce sewage pumping costs within the basin and defer the construction of new interceptors and outfalls.

Computer Modeling of Wastewater Reclamation and Distribution Systems

Because of the size of the study area, a computer model is being developed to investigate the alternative treatment and distribution networks available to meet the needs of the approximately 55 local water purveyors and 450 potential users of the reclaimed water. Within each of the ten service districts in the study area, alternative treatment and distribution networks are sketched and computer modeled to determine the most feasible alternative, based on the water quality requirements of the users.

The computer model enables the rapid analysis of several alternative layouts. Shown in Figure 2 is a typical treatment-distribution layout for transporting reclaimed wastewater to potential users. The influent water quality is that available from the existing tertiary facilities (primary sedimentation, biological oxidation and effluent filtration). A wastewater treatment and industrial pretreatment routine is utilized to model changes in water quality brought about by physical, biological, or chemical treatment steps. These steps can be either additional tertiary processes at the wastewater reclamation plant prior to distribution to all users, or additional treatment steps undertaken at the individual industrial site. As treatment steps are added, the model is re-run to establish new costs.

Several water qualities are defined in terms of constraints to reuse and the time frame of availability of this water. For example, landscape irrigation and some industrial rinsing or cooling operations could potentially use reclaimed water as soon as a distribution system is constructed. These would comprise the first class of users. Industries requiring further wastewater reclamation or pretreatment would comprise a second class, potentially hooked up within four to five years. Projects limited by potential impact of the reclaimed water on the public health, such as groundwater recharge and seawater intrusion barriers, would constitute a third class handled in later time frames. Knowing the water quality constraints for each user will enable the application of various treatment processes which can achieve the desired water quality. Having achieved the desired water quality, then the distribution system can be laid out and the capacity of facilities determined over succeeding time frames. This information is in turn utilized to generate capital and annual costs for both the treatment and distribution network, along with a present worth analysis.

A flow diagram of the computer model developed to predict changes in water quality, capacity of wastewater treatment and industrial pretreatment facilities, and capacity of the distribution system is shown in Figure 3.

Offline reservoir analysis is required since reservoir and storage facilities are highly site and cost specific. The final step in the computer model is a summary statement of facilities size and cost arranged in chronological development by service district. The computer programs required for the complete water quality--water quantity model have been developed by JMM and are online.

As shown in Figure 4, physical, biological, and chemical treatment processes have been modeled to predict the changes in water quality brought about by the respective treatment steps. The input water quality can be either the raw wastewater or wastewater from one of the other treatment processes. For example, if the input water quality is raw sewage then the sedimentation step from physical treatment, the activated sludge step from biological treatment, and lime softening step from the chemical treatment subroutines can be utilized in sequence to yield the output water quality. The chemical treatment model will be discussed in greater detail because of its application to the industrial reuse of municipal wastewater. Most industries will require some form of chemical treatment prior to reuse of reclaimed municipal effluent either in cooling or processes.

By way of illustration, the chemical treatment subroutine will be applied to determine the effects of lime softening of municipal effluent prior to its use in a cooling tower at the Burbank Power Station. The chemical subroutine is an adaptation of a chemical equilibrium model REDEQL2 developed by Morel and Morgan[3] at Cal Tech. The data for complexation and solubility reactions between some 35 metals and 55 ligands are stored in input. The model provides for the precipitation of supersaturated species, the complexation of ions, oxidation and reduction reactions, and adsorption. Major cations and anions included in the model are shown in Figure 5. These cations and anions were judged of particular importance in water intended for industrial reuse. Other metals or ligins can be added as required.

Complexes and ion pairs are considered in the chemical treatment model since they play an important role in tying up ions as the water cycles through industrial processes, especially cooling towers. Complexes between divalent cations, such as calcium and magnesium, and divalent anions, such as sulfate and carbonate are especially extensive. While the sulfate concentration in the treated wastewater may be low, additional sulfate is introduced as a residual from pH control via sulfuric acid addition. At sulfate concentrations approaching 500 mg/l, roughly 40 percent of the calcium in solution is tied up in an ion pair with the sulfate. Any ion paris in solution must be evaluated since they do not precipitate in softening reactions. This results in a much higher concentration of calcium, for example, in solution following softening than predicted by calcium carbonate solubility. The actual calcium level is a function of both the supersaturation of the free calcium ion caused by an incomplete reaction and the ion pair formation. Of the two effects, the calcium carbonate ion pair accounts for the major portion of the residual calcium after softening. Figure 6 is a partial listing of the complexes and ion pairs considered in the chemical treatment model.

Some reactions, such as the adsorption of silica by magnesium hydroxide floc in the softening process are not modeled by the chemical treatment model. A wide disparity exists between different investigators as to the amount of silica adsorbed by the magnesium hydroxide floc. The adsorption may be an ion exchange process with magnesium releasing an hydroxide ion or a co-adsorption of the silica ion with a counter ion. In any event, the engineer must decide on the silica adsorption mechanism which seems reasonable in light of his overall water quality and determine the effluent silica concentration. Figure 7 presents a reasonable relationship between the silica/magnesium ratio in the makeup water to the effluent silica concentration after passing through lime precipitation step, as developed by Matson[4].

The efficiency of chemical reactions is greatly influenced by temperatures and ionic strengths. Higher temperatures accelerate the reaction rates, increase the extent of completion of the reactions, and permit the reactions to be carried out at lower pH's. When temperature is increased most dissolved species increase in solubility. Some materials important in cooling tower and boiler operations, such as calcium carbonate, decrease in solubility as the temperature increases, resulting in greater deposition at higher temperatures. Temperature-solubility relationships used in this study are shown in Figure 8. Many investigators have found an inverse temperature relationship to accurately represent the changes in species solubility. Changes in temperature over the normal operating range of a cooling tower have a substantial influence on the value of the solubility constant. Furthermore, as the model is applied to boilers and other high temperature processes, the relationship of temperature to the equilibrium constant becomes more critical.

Inversely to the temperature relationship, increased ionic strengths reduce the ion activities, and more ion pairs are formed that do not participate in chemical reactions. Ionic strength corrections to reflect reduced activities were made utilizing the Davies equation because it provides the best estimate for waters with ionic strength less than 0.1. The influence of ionic strength on the activity coefficient is significant and cannot be ignored in the calculation of the equilibrium species (Fig. 9).

The equations utilized to correct the equilibrium constants for temperature and ionic strength are shown in Figure 10. Aside from the application of temperature and ionic strength corrections, the equilibrium concentrations of chemical species and the precipitants formed are calculated in a straight-forward iterative mathematical technique.

Practical Application of Chemical Equilibrium Model

As an example of the ability of the chemical equilibrium model to determine the number of cycles of concentration possible in a cooling tower utilizing reclaimed wastewater, JMM engineers studied further the power plant of the Burbank Public Service Department in Los Angeles County. The Public Services Department operates a 6 mgd activated sludge treatment plant with tertiary filtration. Following filtration, the effluent is chlorinated at a dose of 10 mg/l, then flows via gravity for 0.5 mile to the Burbank Power Station where the filtered effluent is utilized to cool the generating units (four steam turbine units providing 154,000 KW). The power station requires 1.6 mgd or roughly 30 percent of the available flow from the wastewater reclamation plant. Excess effluent from the treatment plant is used to dilute the blowdown from the cooling towers or is discharged into the Los Angeles River via a flood control channel.

The Regional Water Quality Control Board requires that the TDS of water entering the Los Angeles River be less than 950 mg/l. The TDS of the reclaimed wastewater entering the cooling towers is 550 mg/l and this restricts the cycles of concentration, unless blowdown dilution is used. Figure 11 illustrates the water quality leaving the filtration plant and entering the power plant as cooling tower makeup. In addition to the high TDS and phosphate concentrations, the reclaimed effluent has a total hardness of 182 mg/l (as $CaCO_3$).

The sulfate concentration of 168 mg/l is increased further by sulfuric acid addition for pH control. The sulfuric acid is added at the base of the cooling towers (Fig. 12) to reduce the alkalinity and establish a pH of 6.5.

Following the sulfuric acid addition for pH and alkalinity control, the Burbank Power Station must add: polyphosphates for corrosion control, phosphonates (4 mg/l) for $Ca_3(PO_4)_2$ destabilization, polyacrylates (6 mg/l) for suspended solids dispersion, chlorine dioxide for biological/algal control, and antifoaming agents for dispersion of foam caused by phosphates and organic molecules. The antifoaming agent is expensive, but is often required when reclaimed municipal effluent is utilized in cooling towers. The cost of these internal treatment steps, currently $147/million gallons, plus the presence of hardness ions in the reclaimed effluent indicated that another external treatment step, i.e. lime softening at the wastewater reclamation plant, might be justified.

Using the chemical equilibrium model, the untreated makeup water was found to be supersaturated in tricalcium phosphate after only two cycles of concentration; with 53 percent of the total available calcium and 98 percent of the total available phosphate precipitating as tricalcium phosphate. Furthermore, because of the high initial concentration of calcium and phosphate, the amount of tricalcium phosphate formed was large, approximately 118 mg/l. As shown in Figure 13, at higher cycles of concentration, fluorite (CaF_2) and silica are also supersaturated; however, the quantities involved are small. The chemical equilibrium model explains why operating experience at the Burbank Power Station dictates a high dose of phosphonate to destabilize tricalcium phosphate.

The effect of lime-softening of the makeup water can be seen in Figure 14, where the chemical equilibrium model predicts which species will precipitate as the pH is raised from 7.5 to 11.5. The model predicts that at a pH of 10.5, 68 percent of the calcium, 100 percent of the phosphate, 98 percent of the carbonate, and 94 percent of the magnesium will precipitate from solution. In addition, the silica concentration will be reduced to 10 mg/l by adsorption on the manganese hydroxide floc.

Following lime-softening, the pH is lower via sulfuric acid addition to 6.5, and then the precipitants at various cycles of concentration are determined by rerunning the equilibrium model as shown in Figure 15. Only fluorite is supersaturated in the lime softening makeup water for cycles of concentration less than 10. At four cycles of concentration, the fluorite level is only 2 mg/l. By 20 cycles of concentration, the fluorite level has increased to 40 mg/l. In addition, calcium carbonate has precipitated to the extent of 470 mg/l and silica to 80 mg/l. Nevertheless, following lime softening, at least 10 cycles of concentration could be achieved via minor addition of phosphonates to destabilize fluoride. No other species are predicted to precipitate through at least ten cycles of concentration.

The intent of the lime-softening is to produce a low-salt makeup water which can be added to the base of the cooling tower as shown in Figure 16. This low-salt makeup may require some internal chemical treatment steps, such as sulfuric acid addition for pH control and polyphosphates for corrosion control. However, overall internal treatment should be greatly reduced. The makeup water together with the recycled cooling water passes through the industrial process, in this case a heat exchanger, and then recycles back to the cooling tower. Some blowdown of high salt water will be required to maintain an overall salt balance in the cooling tower. The quantity of blowdown following lime-softening will be significantly less than when untreated effluent was used, since greater cycles of concentration can be achieved with the low-salt makeup water.

Lime softening adds $100/million gallons to the cost of the reclaimed effluent, but may produce substantial reductions in internal chemical treatment costs and will enable ten cycles of concentration to be achieved thereby reducing blowdown and makeup. The cost of lime softening is $43/million gallons for capital expenses and $55/million gallons for operation and maintenance expenses, as shown in Figure 17. Without undergoing pilot testing, an accurate estimate could not be made of the reductions in internal treatment cost expected because of the lime softening process. The savings should be substantial because of the removal of calcium and phosphate.

Operating personnel at the Burbank Station stated that the internal chemical treatment, i.e. polyphosphates, phosphonates, polyacrylates, and chlorine dioxide cost \$147/million gallons irrespective of whether raw water or reclaimed effluent was used. Some advantages accrue in the use of raw water since the amount of phosphonates required for tricalcium phosphate destabilization is reduced, as is the requirement for antifoam agents. Lime softening the reclaimed effluent should further reduce chemical costs. However, for comparative purposes they have been set at \$147/million gallons until better data are available.

As shown in Figure 18, at the present time the Burbank Power Station utilizes 1.6 mgd of reclaimed wastewater at a recycling rate of 2.5. Approximately one million gallons/day is lost via evaporation and 600,000 gallons/day via blowdown. This blowdown must be diluted either by additional raw water or reclaimed effluent to permit its discharge into the Los Angeles River, where the Regional Water Quality Control Board has mandated that the TDS be less than 950 mg/l. This requirement for blowdown dilution essentially doubles the cost of reclaimed water usage from \$460/million gallons/day to \$1,070/day. If the reclaimed effluent was lime softened, then the cycles of concentration could be increased to ten, thereby reducing the amount of blowdonw to 100,000 gallons/day. The requirement for blowdown dilution is similarly reduced and this results in a total water cost, with blowdown dilution, of \$960/day. Use of either the reclaimed effluent or the lime-softened effluent provides a substantial reduction in daily water cost over the use of raw, fresh water. Further advantages would accrue to the lime-softened effluent since internal treatment practices can probably be reduced as calcium phosphate, magnesium hydroxide, and silica are precipitated.

Conclusion

At the present time JMM is gathering data so that the total computer model can be utilized to evaluate the treatment and distribution system alternatives available in the Los Angeles/Orange County areas. The chemical equilibrium model will be applied to the various classes of users to further refine the alternative treatment means and the resulting water quality. For cooling towers, or any hot processes in which minerals will be concentrated, such as boilers, the model can simulate the effect of cycles of concentration on each species.

For each class of users within a service area, one or more reasonable pretreatment/water quality arrangements will be chosen and utilized as input data for the reclaimed water supply model. This model is then used to calculate the size and cost of capital facilities such as treatment units, distribution pipelines, pump stations, and storage reservoirs. The locations of the treatment plants and pipelines and the size of the users water demands must be specified by the engineer. The model then sizes pipes, storage facilities, and pumps to provide the water at the desired quantity and pressure. Finally, the information is transmitted to an economic analyses routine in which the present worth of the facilities is calculated. By altering the location of facilities, adding or subtracting potential users or classes of users, and rerunning the reclaimed water supply and economic analyses models, alternative systems and their costs may be rapidly analyzed.

A second set of water quality requirements will be established for the second class of users. The treatment techniques required to achieve their water quality requirements will be evaluated in the chemical equilibrium model. Once the treatment requirements and user quantity demands have been defined, then a second distribution network which includes these users and their pretreatment facilities can be superimposed on the initial set of earlier users. These data are in turn transmitted to the reclaimed water supply and economic analyses models. Iteration of this routine, each time including additional users with more extensive treatment requirements, will generate a series of alternative systems and costs from which reasonable choices are made. The output from each stage within each service district may then be combined with the output from other service districts and an overall regional scheme defined.

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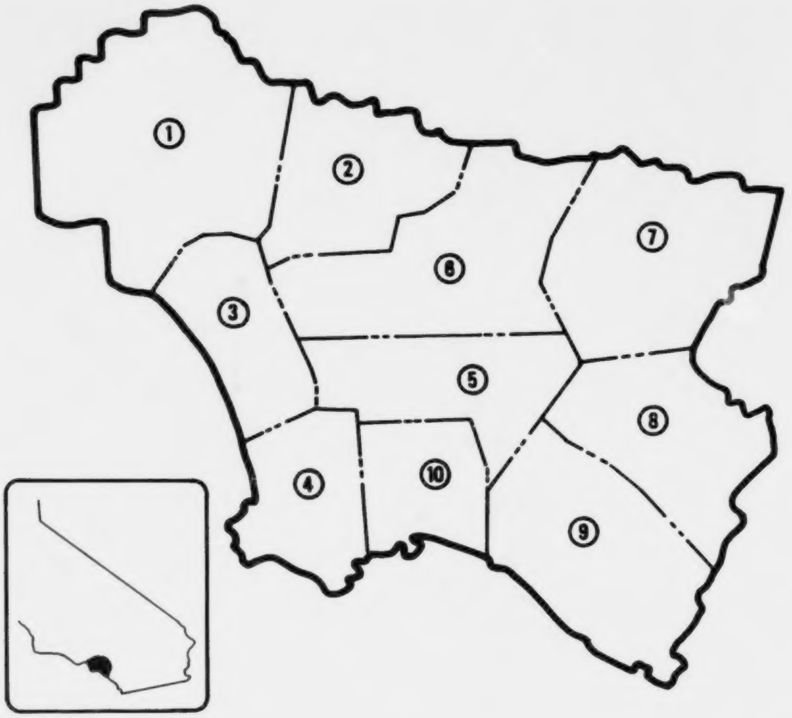
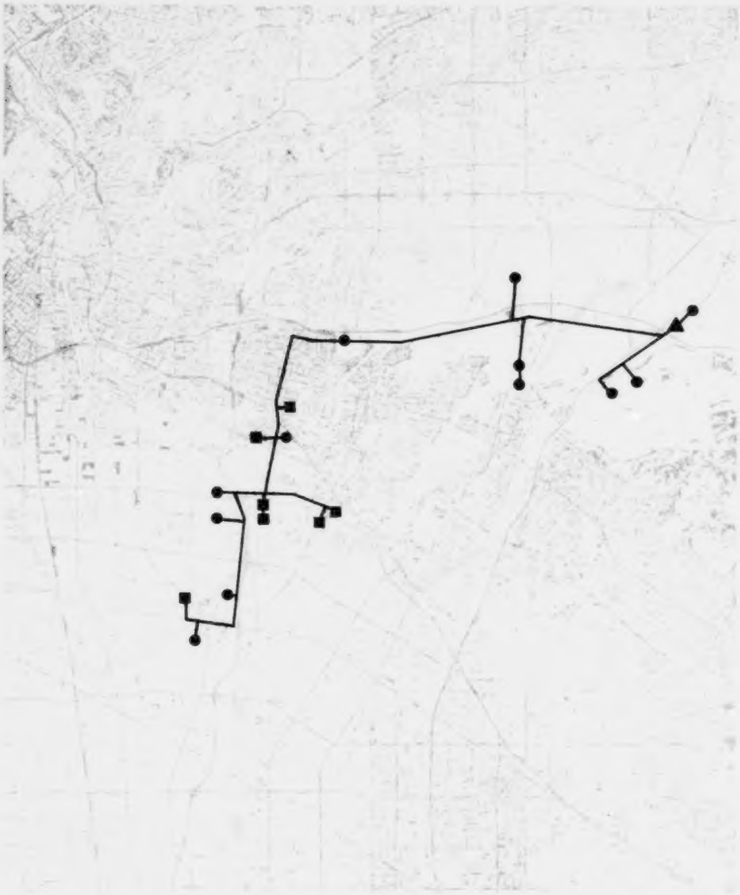


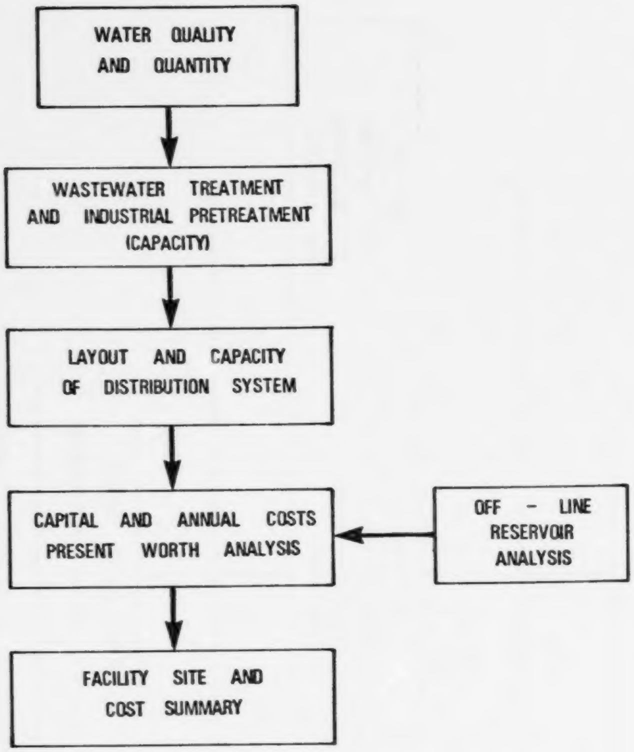
THE LOS ANGELES/ORANGE COUNTY REUSE STUDY AREA HAS BEEN DIVIDED INTO TEN SERVICE DISTRICTS CORRESPONDING TO WATER QUALITY REQUIREMENTS OF POTENTIAL USERS AND AVAILABLE RECLAMATION FACILITIES

FIGURE I



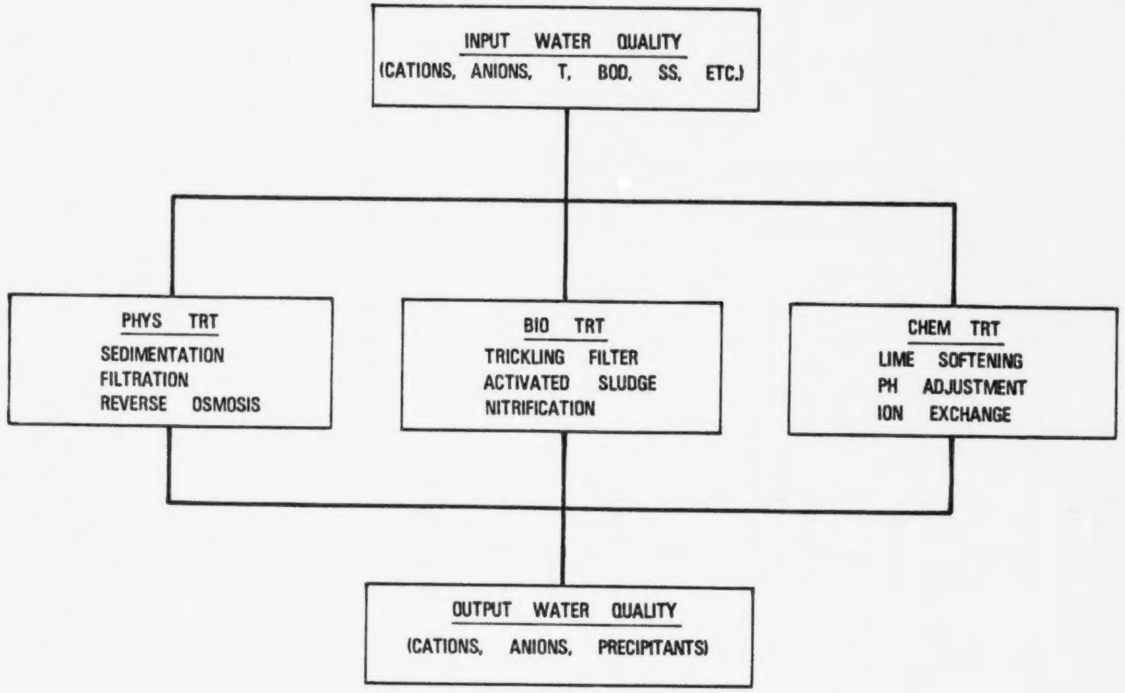
THE WATER REUSE MODEL
COMPUTERIZES THE WATER QUANTITY
AND WATER QUALITY REQUIREMENTS
OF INDUSTRIAL USERS WITHIN A SERVICE DISTRICT

FIGURE 2


WATER QUALITY AND QUANTITY
WASTEWATER TREATMENT AND INDUSTRIAL PRETREATMENT (CAPACITY)
LAYOUT AND CAPACITY OF DISTRIBUTION SYSTEM
CAPITAL AND ANNUAL COSTS PRESENT WORTH ANALYSIS
OFF - LINE RESERVOIR ANALYSIS
FACILITY SITE AND COST SUMMARY

THE REUSE MODEL CALCULATES
CHANGES IN WATER QUALITY BROUGHT
ABOUT BY VARIOUS TREATMENT
STEPS, AND ESTIMATES THE
COST OF TREATMENT AND DISTRIBUTION
SYSTEM FACILITIES

FIGURE 3



CHANGES IN WATER QUALITY BROUGHT ABOUT BY PHYSICAL, BIOLOGICAL, AND CHEMICAL TREATMENT STEPS HAVE BEEN MODELED TO PROVIDE EFFLUENT WATER QUALITY

FIGURE 4

CHEM TRT MODELS
MAJOR CATIONS AND ANIONS
IMPORTANT IN WATER AND
WASTEWATER PROCESSES

FIGURE 5

H^{+}

N_a^{+}

K^{+}

C_a^{+2}

M_g^{+2}

M_n^{+2}

Z_n^{+2}

P_b^{+2}

C_r^{+3}

F_e^{+2}

F_e^{+3}

Al^{+3}

OH^{-}

NO_3^{-}

F^{-}

$C\ell^{-}$

CO_3^{-2}

SO_4^{-2}

$S_iO_2(OH)_2^{-2}$

PO_4^{-3}

CHEM TRT MODELS
COMPLEXES AND ION PAIRS

FIGURE 6

CARBONATE COMPLEXES

$C_aHCO_3^{+}$

$M_gHCO_3^{+}$

$C_aCO_3^{\circ}$

$M_gCO_3^{\circ}$

PHOSPHATE COMPLEXES

$C_aH_2PO_4^{+}$

$C_aPO_4^{-}$

$M_gH_2PO_4^{+}$

$M_gPO_4^{-}$

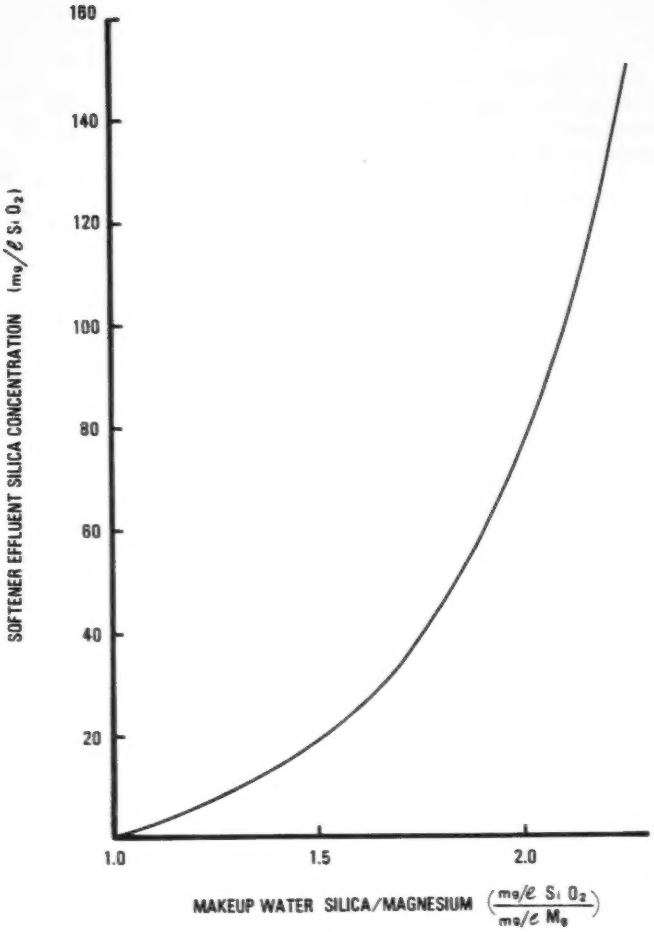
$C_aHPO_4^{\circ}$

$M_gHPO_4^{\circ}$

HYDROXY COMPLEXES

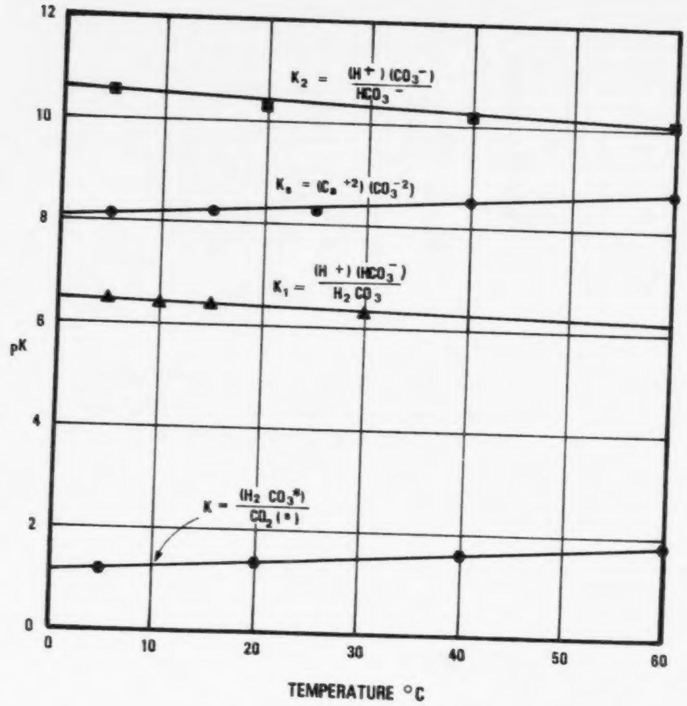
C_aOH^{+}

M_gOH^{+}



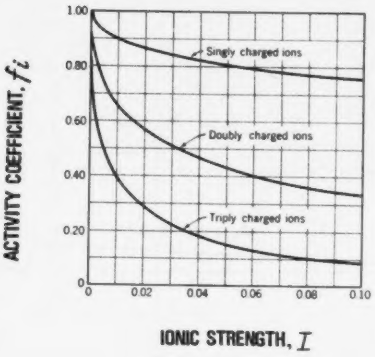
THE SILICA CONCENTRATION IN THE EFFLUENT
FROM THE LIME SOFTENER CAN BE
RELATED TO THE SILICA/MAGNESIUM
RATIO IN THE INFLUENT MAKEUP WATER (4)

FIGURE 7



WITH THE EXCEPTION OF CALCIUM CARBONATE, THE SOLUBILITY OF MOST SPECIES INCREASES WITH INCREASING TEMPERATURES OVER THE OPERATING RANGE OF COOLING TOWERS - HEAT EXCHANGES

FIGURE 8



THE ACTIVITIES OF IONS IN SOLUTION
ARE GREATLY REDUCED BY INCREASES
IN THE IONIC CONTENT OF THE SOLUTION

FIGURE 9

TEMPERATURE :

$$-\log K = AT + C/T - D$$

WHERE $T =$ °K (ABSOLUTE)

IONIC STRENGTH

$$-\log F_i = -A Z_i^2 \left[\frac{\sqrt{I}}{1+\sqrt{I}} - 0.3\ I \right]$$

WHERE $F_i =$ ACTIVITY COEFFICIENT

$Z_i =$ IONIC CHARGE

$I =$ IONIC STRENGTH

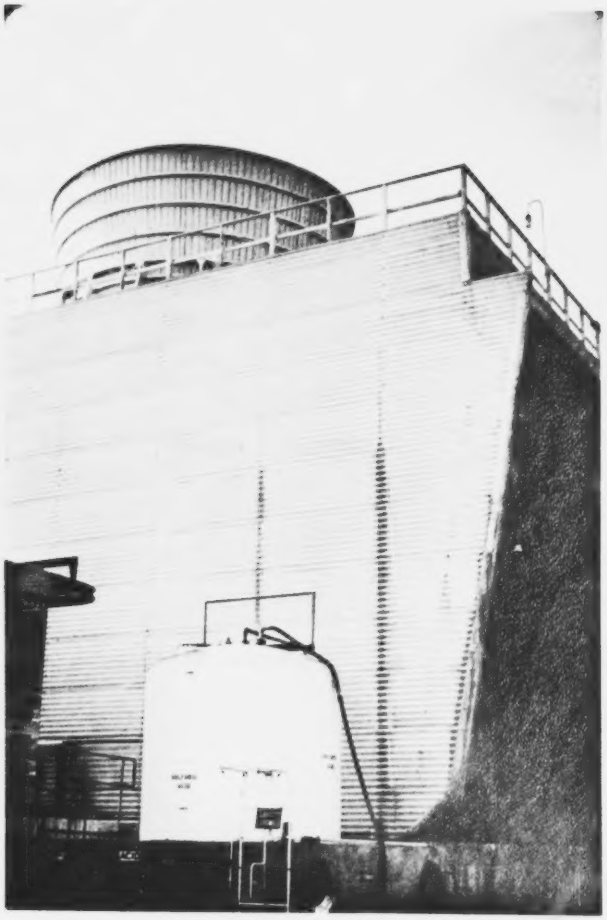
CHEM TRT PERFORMS TEMPERATURE
AND IONIC STRENGTH CORRECTIONS

FIGURE 10

CATIONS	mg/ℓ	ANIONS	mg/ℓ
N_a^{+1}	89	$C\ell^{-1}$	90
C_a^{+2}	47	F^{-1}	1
M_g^{+2}	16	NO_3^{-1}	26
		SO_4^{-2}	168
		PO_4^{-2}	36
		$H_2S_iO_4^{-2}$	19
p^H	7.15 UNITS	ALKALINITY ($C_a CO_3$)	172

EFFLUENT FROM ACTIVATED SLUDGE –
FILTRATION TREATMENT PLANT IS
COOLING TOWER MAKEUP

FIGURE II



SULFURIC ACID IS USED TO NEUTRALIZE
ALKALINITY AND ESTABLISH AN
ACIDIC pH IN RECLAIMED WASTEWATER
USED AT THE BURBANK POWER STATION
COOLING TOWERS

FIGURE 12

CYCLES OF CONCENTRATION	PERCENT OF CATION/ANION IN PRECIPITANT		
	$Ca_3(PO_4)_2$	CaF_2	SiO_2
2	53/98		
3	54/99		
4	54/99		
5	54/100	1/18	
6	54/100	1/33	
7	54/100	1/47	11
8	54/100	1/51	22
9	54/100	1/58	31
10	54/100	2/61	38

UNTREATED MAKEUP WATER IS SUPERSATURATED IN CALCIUM PHOSPHATE AFTER 2 CYCLES OF CONCENTRATION

FIGURE 13

	PERCENT OF CATION/ANION IN PRECIPITANT		
pH	$Ca_3(PO_4)_2$	$CaCO_3$	$Mg(OH)_2$
7.5	22/100		
8.0	22/100	16/35	
8.5	22/100	34/72	
9.0	22/100	41/88	
9.5	22/100	44/95	
10.0	22/100	45/97	41
10.5	22/100	46/98	94
11.0	22/100	46/98	99
11.5	22/100	46/98	100

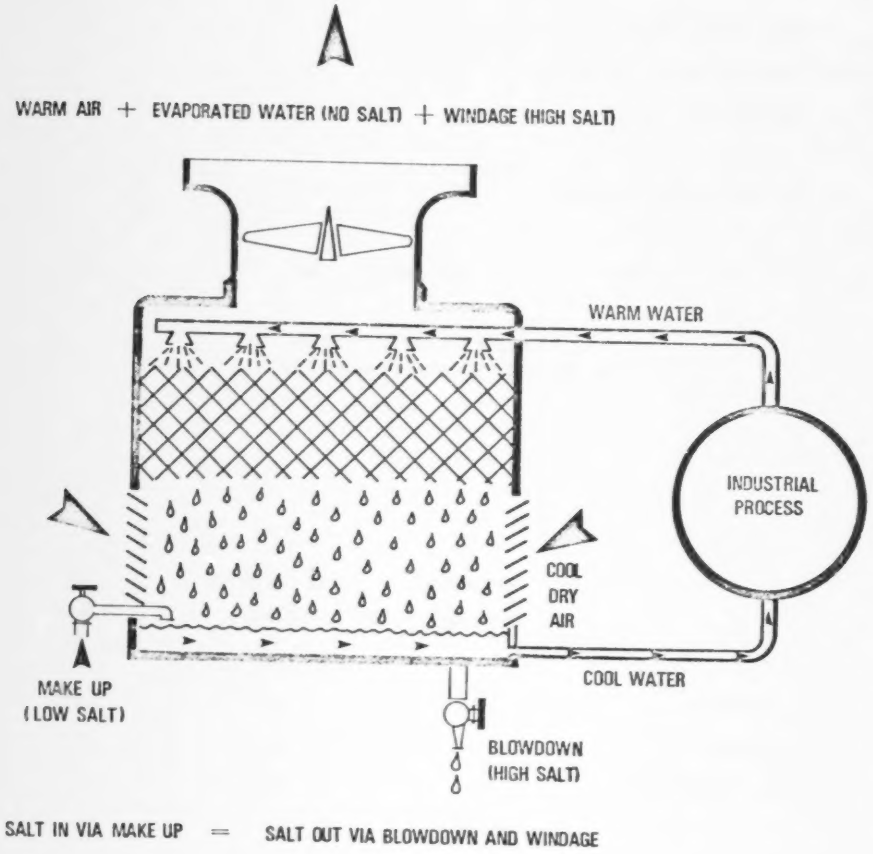
LIME SOFTENING OF MAKEUP WATER TO pH 10.5 WILL REMOVE CALCIUM, MAGNESIUM, AND PHOSPHATE IONS

FIGURE 14

CYCLES OF CONCENTRATION	PERCENT OF CATION / ANION IN PRECIPITANT			
	CaF_2	$CaCO_3$	SiO_2	$CaSO_4$
2				
3				
4	1/24			
5	1/42			
6	2/53			
7	2/60			
10	2/70			
20	3/86	25/18	40	
30	3/89	45/32	60	7/3

ONLY FLUORITE IS SUPERSATURATED
IN LIME SOFTENED MAKEUP
WATER FOR CC < 10

FIGURE 15


WARM AIR + EVAPORATED WATER (NO SALT) + WINDAGE (HIGH SALT)
WARM WATER
INDUSTRIAL PROCESS
COOL DRY AIR
COOL WATER
MAKE UP (LOW SALT)
BLOWDOWN (HIGH SALT)
SALT IN VIA MAKE UP = SALT OUT VIA BLOWDOWN AND WINDAGE

SALT BALANCE IN COOLING TOWER

FIGURE 16

TREATMENT STEPS	COST ($ / MIL GAL) RECLAIMED EFFLUENT	LIME - SOFTENED EFFLUENT	RAW WATER
WELL/COLO. R. WATER			414
ACTIVATED SLUDGE / FILTRATION	141	141	
LIME SOFTENING : CAPITAL		43	
O & M		55	
INTERNAL CHEMICAL TREATMENT	147	147	147
TOTAL	288	386	561

LIME SOFTENING ADDS $100/MIL GAL TO COST OF RECLAIMED EFFLUENT

FIGURE 17

	RECLAIMED EFFLUENT	LIME SOFTENED EFFLUENT	RAW WATER
		WATER USE (MIL GAL/DAY)	
EVAPORATION	1.0	1.0	1.0
BLOWDOWN	0.6	0.1	0.6
BLOWDOWN DILUTION	2.1	1.4	0.9
TOTAL	3.7	2.5	2.5
		WATER COST ($/DAY)	
W/O DILUTION	460	420	900
W/ DILUTION	1070	960	1400

DILUTION OF BLOWDOWN DOUBLES THE COST OF RECLAIMED WATER USAGE

FIGURE 18

EFFECTS OF EPA GUIDELINES
ON INDUSTRIAL WATER REUSE

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Reston, Virginia

ABSTRACT

The purpose of this discussion is to highlight Federal regulatory statutes that are contributing to the increased reuse of industrial process waters. Primarily, these effects are a result of stringent regulations governing the discharge of toxic pollutants. As a result of these regulatory limitations, conventional methods for controlling water pollution are becoming unattractive. The marginal costs of conventional treatment are becoming exceedingly high as the required percentage of pollutant removal increases and as the technical limits of pollutant removal are being approached.

In addition to these stringent limitations imposed by Federal statutes that indirectly force water reuse, the new Amendments to the Federal Water Pollution Control Act specifically allow for an extension in meeting regulations if innovative technologies (e.g., water reuse) are used in pollution control. These and other factors are discussed in the text.

The terms reuse, recycle, and recovery are becoming very popular in discussions of industrial water use. There are several major trends responsible for their increased popularity.

- Emphasis on Water Conservation
- Development of Technologies for Recovery of Process Chemicals
- Regulatory Statutes

Water conservation is an important factor in maintaining adequate water supplies, particularly in arid regions of our country. This was recognized by the State of California when repeated cycles of drought and flooding prompted them to allow allocations of fresh water to industry only if manufacturing facilities prove an inability to operate on reused water or an inability to locate reused sources. In the Gulf Coast area and other United States regions, water conservation and reuse are stimulated by land subsidance problems that have resulted in a steady drop in water tables.

Concerning the second trend, new technologies are being applied to waste streams for the recovery of valuable process chemicals. Although in most cases the decision to use recovery technologies is basically one of economics, the plants using recovery techniques are realizing the added bonus of clean water that can be reused in many manufacturing processes.

One example of increased use of recovery is found in the metal finishing industry. According to a recent survey, over 600 electroplating plants are currently using advanced techniques such as ion exchange and reverse osmosis to recover metal ions in rinsewaters. Some of these systems are efficient enough to act as closed-loop operations.

In the past, the decision to utilize recovery techniques was simply made by weighing the capital and operating costs against the savings in chemicals and other raw materials. For most operations, recovery was not cost effective. However, with the effect of our third-factor regulatory statutes, the decision now must account for additional savings in expensive wastewater treatment. Primarily, these effects are a result of stringent regulations governing the discharge of toxic pollutants. Under mandate, the Environmental Protection Agency (EPA) is relaxing efforts to control conventional oxygen-depleating pollutants and is concentrating on controlling minute amounts of cancer-causing substances. As a result, end-of-pipe conventional technologies for controlling water pollution are becoming unattractive. The marginal costs of conventional treatment are becoming exceedingly high as the percentage of required pollutant removal increases and as the technical limits of pollutant removal are being approached by the imposed regulations. In many cases, conventional treatment removes little or none of the toxic substances. To avoid the use of expensive, ineffective conventional treatment methods, industry must either alter manufacturing processes or institute technologies that reduce or eliminate toxic discharges. Obviously, process water recycle, or reuse, will be a major consideration.

The remainder of this discussion will focus upon these regulatory statutes that control toxic pollutants and that contribute to the increased reuse of industrial process waters.

First, as an overview, let us consider the general regulatory scenario for the control of toxics. Table 1 lists 13 Federal statutes that are involved in the control of human and environmental exposure to toxic compounds.

These regulatory statutes have a very broad impact upon the industrial and public sectors. The Toxic Substances Control Act allows the Administrator of EPA to prohibit the manufacture or distribution of a substance when it presents an unreasonable risk of injury to health or the environment. The Federal Insecticide, Fungicide and Rodenticide Act requires manufacturers to register any pesticides with EPA's Administrator, after which it is classified for general or restricted use depending upon the potential for adverse environmental effects.

The Ocean Dumping Act mandated a permit system intended to regulate the dumping of any material into ocean waters if it adversely affects human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities. The Act specifically calls for an end to dumping sewage sludge into ocean waters no later than December 31, 1981.

The Safe Water Drinking Act, which incidently calls for a program of potable reuse research, allows the EPA to promulgate regulations governing maximum allowable contaminant levels in public water supplies.

The Clean Air Act, Resource Conservation and Recovery Act, and Clean Water Act are perhaps the most widely recognized environmental regulatory statutes. These acts provide for human and environmental protection from industrial and public pollution sources for the various pollution media. Together with the other statutes previously discussed or listed in Table 1, these acts provide rather comprehensive coverage for toxic regulation. Figure 1 dramatically depicts their interrelationships.

Examining the regulator scenario in the case of an industry (shaded blocks in Figure 1), TSCA may require the physical treatment of a product to remove a potentially toxic compound. Wastewater containing the contaminate will thus be generated. If the toxic material is one of the chemical substances designated by the Clean Water Act, then the wastewater must be treated to remove that material.

The wastewater treatment may lead to the generation of solid waste or sludge that contains that same toxic material. The management of this solid material must then comply with forthcoming regulations to be administered under RCRA. If the solid waste must be burned, then the emissions from incineration will be regulated under the Clean Air Act.

The alternative to this scenario that may provide relief from the tortures of environmental regulations is industrial process water recycle or reuse. This option could eliminate this cycle for toxic materials flow and the potential for toxic accumulation within the environment by eliminating toxic wastewater flows.

At this point, the discussion will concentrate on the environmental statute that most directly affects industrial water reuse. This, of course, is the Clean Water Act; one of the more substantive environmental lawsin the United States. To adequately describe the effects of the Act, a brief history of legislature development will be presented. Also, the most relative portions of the Act will be described along with current rule-making efforts.

Table 2 outlines the history of the Clean Water Act development which dates back at least to 1956 with the passage of the original Federal Water Pollution Control Act. In 1972, the Federal Water Pollution Control Act amendments replaced the previous language of the original act entirely, including the Water Quality Act of 1965, the Clear Water Restoration Act of 1966, and the Water Quality Improvement Act of 1970, all of which had been amendments of the original act passed in 1956.

The Settlement Agreement of 1976, which was a Federal District Court action, forced EPA to establish standards for toxic compounds. Influenced by the Settlement Agreement, the Clean Water Act of 1977 further amended the Federal Water Pollution Control Act.

Without dwelling on the previous statutes, some of the industrial regulatory aspects of the 1972 amendments to be discussed include:

- BPCTCA (Average of the Best) 1977
- BATEA (The Best) 1983
- BADCT (New Sources)
- Section 307 (A) Toxic Pollutants
  (B) Pretreatment

The 1972 amendments identified several major environmental goals for the nation. These goals were later preserved by the 1977 amendments. They include eliminating the discharge of pollutants into navigable waters by 1985, obviously an advancement for reuse; providing for fishable and swimmable waters by 1983, which was termed an interim goal; and limiting the hazards of toxic pollutants.

To meet these goals, the 1972 amendments established various levels of effluent limitations to be determined by the EPA for industrial point sources.

The first two levels of effluent limitation received the most attention by EPA. These are the best practical control technology currently available, and the best available technology economically achievable. These are a step-wise increase in control technology intended to force all industrial discharges to use the technology by 1977 that was an average of the best, and to use a technology that was the best by 1983. The 1977 limitations were geared toward end-of-pipe treatment. The 1983 regulations included end-of-pipe treatment, and also internal control which included the reuse of process waters.

Other limitations of the 1972 amendments included the best available demonstrated control technology, which pertained to new industrial facilities, and the Section 307 limitations which cover toxic pollutants and also pretreatment for indirect dischargers.

Between the time the 1972 amendments were enacted and 1976, the EPA concentrated on developing the 1977 or best practical limitations, and the 1983 or best available limitations, for pollutants such as BOD and TSS, which are the major contributors of pollution.

Although the Agency had been required to establish standards for toxic materials, only proposed standards for six specific toxics have been developed. Because the Agency had not followed the mandate to establish standards for toxic substances, five public interest groups filed civil action suits in the United States District Court in the District of Columbia against the Agency (National Resources Defense Council vs. Train). The suits resulted in the Settlement Agreement on June 7, 1976. The Settlement Agreement, a Constant Decree, or Flanery Decision required the EPA to promulgate standards for toxics within three years.

The requirements of the Settlement Agreement are summarized below:

- Effluent limitations based on the best available technology economically achievable (BATEA).
- New source performance standards (NSPS) based on the best available demonstrated control technology (BADT).
- Pretreatment standards for existing sources (PSES) for discharges to publicly owned treatment works.
- Pretreatment standards for new sources (PSNS) for discharges to publicly owned treatment works.

For 21 industry categories, later termed primary industries, the EPA was required to promulgate regulations for 65 classes of compounds considered to be toxic. The limitations were expected to supplement or replace existing 1983 or best available technology limitations, as well as covering new sources and pretreatment limitations for both the existing and new sources.

The 21 industries covered by the Settlement Agreement which included most of the non-food industries are listed in Table 3.

The list of 65 classes of compounds that were to be examined for each of the 21 industries came from a special agency work group that included environmental groups and private consultants. Originally that special work group identified 232 candidate substances from a number of sources. Among others, those sources included the EPA itself, the Environmental Defense Fund, the National Resource Defense Counsel, and the National Cancer Institute. Those 232 substances were examined for:

- Human carcinogens
- Aquatic toxicity
- Other chronic toxicity
- Bioaccumulation
- Occurrence in effluents, aquatic environment, fish, and drinking water

Based on this analysis, the 232 substances were reduced to the famous 65 compounds.

As mentioned earlier, the Settlement Agreement and the 1972 amendments to the Water Pollution Control Act were the basis for the regulatory aspects of the Clear Water Act of 1977. At this point, will be discussed the Clean Water Act which is the present environmental statute.

The goals of the Clean Water Act are identical to those of the 1972 amendments: eliminating the discharge of pollutants into navigable waters by 1985; providing for fishable and swimmable waters by 1983; and eliminating the hazards of toxic compounds. However, there were some major changes to the 1972 amendments concerning the types of regulations for meeting these goals. These major changes are summarized and discussed below:

- Toxic Compounds
    - 65 Compounds
    - July 1, 1984 BATEA
    - July 1, 1980 Effluent Limitation
- Conventional Pollutants
    - July 1, 1984 BCPCT
    - $\mathrm{BPCTCA} \leq \mathrm{BCPCT} \leq \mathrm{BATEA}$
- Nonconventional Pollutants
    - July 1, 1987 BATEA
    - Possible Waiver

The first major change was to create three categories of pollutants. The toxic compounds became the major focus of the new law. The compounds referred to in the Act are the same 65 compounds that were associated with the Settlement Agreement. These toxic pollutants are subject to effluent limitations resulting from the applications of the best available technology to be installed by industry no later than July 1, 1984. All other toxic substances subsequently added to the list must achieve BAT limitations no later than three years after the limitation is established. The regulations, or effluent limitations, must be determined by EPA no later than July 1, 1980, to allow industries time to install the appropriate technologies.

The conventional pollutants, which include BOD, TSS, fecal coliforms, pH, COD, phosphorus, and oil and grease, must be controlled to their effluent limitation, also by July 1, 1984. The level of technology of these regulations is defined as the best conventional pollutant control technology. The intent of the act was to establish the best conventional technology somewhere in the interval of the best practical technology, the old 1977 regulations, and the best available technology, the old 1983 regulations, both of which were promulgated under the 1972 amendment.

Nonconventional pollutants, which are other than conventional pollutants and also nontoxic, and which may include such pollutants as color, must be controlled by the best available technology no later than July 1, 1987. A discharger of nonconventional pollutants may apply for a modification, if the modified requirement will not interfere with water quality.

The author should emphasize that the Act provides that effluent limitations are to be achieved by these dates based on the described technologies. Industries are required to treat their discharges to a degree made possible by these technologies, but they are not required to use any particular method of pollution control. Any method will do, so long as the treated effluent meets the parameters set forth in the standards.

Since most standards are written on a mass-per-unit of production basis, it may be more economical to meet the standards with an innovative reuse technology. These technologies could concentrate the waste stream for easier end-of-pipe treatment or could allow for the recovery of valuable process chemicals.

Another change to the 1972 amendments concerning control technologies is the innovative technology extension. This section of the Clean Water Act permits an extension of the best available technology requirements for industrial sources that utilize innovative technologies such as reuse or recycle. The extension can be granted until July 1, 1987 if the process will achieve significantly greater effluent reduction than BAT at a similar cost or if it will allow compliance with existing requirements at significantly reduced costs. In either case, the system must have potential for industry-wide application.

Now that the author has discussed the regulatory requirements of the Clean Water Act, a brief review will be presented of the methodology that EPA has been using to establish the limitations.

First of all, let us look at the administrative structure for water pollution regulations (Figure 2). At the top of the management structure is the Administrator of EPA, Douglas Costol. Within the next level is the Assistant Administrator for Water and Hazardous Waste Materials, who is presently Thomas Jorling. Within the next level is the Water Planning and Standards Group, which is led by a Deputy Assistant Administrator, Swep Davis. Under Mr. Davis there are several major groups responsible for developing the limitations and administering support studies. Specifically, the Criteria and Standards Division and the Monitoring and Data Support Division are responsible for determining the environmental significance of the pollutants. Studies are conducted pertaining to the potential human-related or ecological-related hazards of the pollutants.

The Office of Analysis and Evaluation is responsible for assessing the potential economic impact of controlling the pollutants. The Effluent Guidelines Division is responsible for determining the waste loads, evaluating alternative technologies, determining costs, and establishing the levels of pollutant reduction that can be achieved.

These technical studies are perhaps the heart of the regulation development. The studies are very comprehensive and involve literature searches, data requests from industry, extensive waste water sampling and analysis, and evaluation of technical alternatives. The sampling and analysis efforts take months to complete. For the Pulp and Paper Program alone, over 100 mills were visited by sampling crews from either EPA or a technical contractor. At each location, several days of composite sampling was performed to establish wastewater characteristics and to determine the effectiveness of treatment and internal control.

The typical procedure for promulgating a toxic regulation for a primary industry is depicted in Figure 3. Environment and health studies, technology studies, and economic impact studies are performed simultaneously by separate divisions. These studies are combined by a working group committee and the proposed guidelines are developed and published. After receiving public comment on the proposed regulations,the appropriate changes are made, and the final regulations are promulgated.

The development of regulations for secondary industries, which are mostly the food industries, is less comprehensive. Instead of pursuing new data, the program relies upon past studies; development documents, and economic analysis documents are reviewed for technical and cost information.

The economic reasonableness of the past regulations is then determined by applying a cost test. The present cost test compares the marginal cost of meeting regulations for specific industries against the marginal cost for treatment by municipal works. If the costs are greater for the municipality, then the regulations for industry are considered reasonable.

In summary, along with an increased emphasis on water conservation and the development of reuse technologies, environmental statutes are contributing to an increased reuse of industrial process waters.The environmental regulatory scenario is very complex. The regulations are reaching past the obvious problems of BOD and TSS, and are concentrating on the more difficult toxic pollutants.

The stringency of the new regulations is such that end-of-pipe treatment cannot economically reduce pollutant discharges. More and more, it is becoming necessary to utilize reuse technologies as an alernative to the end-of-pipe treatment.

Further, the development of reuse technologies is being stimulated by the extensions to the regulatory requirements for innovative technologies. Clearly, the regulatory statutes point toward reuse as a final solution to the control of water pollution and reduced exposure to toxic substances.

TABLE 1

Regulatory Statutes

Toxic Substance Act of 1976, (TSCA), P.L. 94-469.

Food, Drug and Cosmetic Act as amended in 1976.

Occupational Safety and Health Act of 1970, (OSHA), P.L. 92-573.

Poison Prevention Packaging Act of 1970, (PPPA), P.L. 81-601 [and superceded by CPSA].

Federal Hazardous Substances Act as amended in 1971, (FHSA) [and superceded by CPSA].

Marine Protection Research and Sanctuaries Act of 1972, (Ocean Dumping Act), P.L. 92-532.

Federal Insecticide, Fungicide and Rodenticide Act as amended in 1972, (FIFRA), P.L. 92-516.

Clean Air Act as amended in 1977, (CAA), P.L. 95-95.

Federal Water Pollution Control Act as amended in 1977, (FWPCA), P.L. 95-217 [Clean Water Act].

Safe Drinking Water Act of 1974, (SWDA), D.L. 93-523.

Resource Conservation and Recovery Act of 1970, (RCRA), P.L. 94-580.

Hazardous Materials Transportation Act, (HMTA).

National Environmental Policy Act of 1969 (NEPA).

TABLE 2

History of Clean Water Act Development

1956 - Federal Water Pollution Control Act

1965 - Water Quality Act

1966 - Clean Water Restoration Act

1970 - Water Quality Improvement Act

1972 - Federal Water Pollution Control Act Amendments, P.L 92-599

1978 - Settlement Agreement

1977 - Clean Water Act of 1977, P.L. 95-217

TABLE 3

Industries Covered by Consent Decree

Timber products processing

Leather tanning and finishing

Steam electric power plants

Iron and steel manufacturing

Petroleum refining

Nonferrous metals manufacturing

Paint and ink formulation and printing

Auto and other laundries

Paving and roofing materials

Ore mining and dressing

Coal mining

Textile mills

Soap and detergent manufacturing

Plastic and synthetic materials manufacturing

Pulp and paperboard mills; converted paper products

Rubber processing

Miscellaneous chemicals

Machinery and mechanical products manufacturing

Electroplating

Inorganic chemicals manufacturing

Organic chemical manufacturing

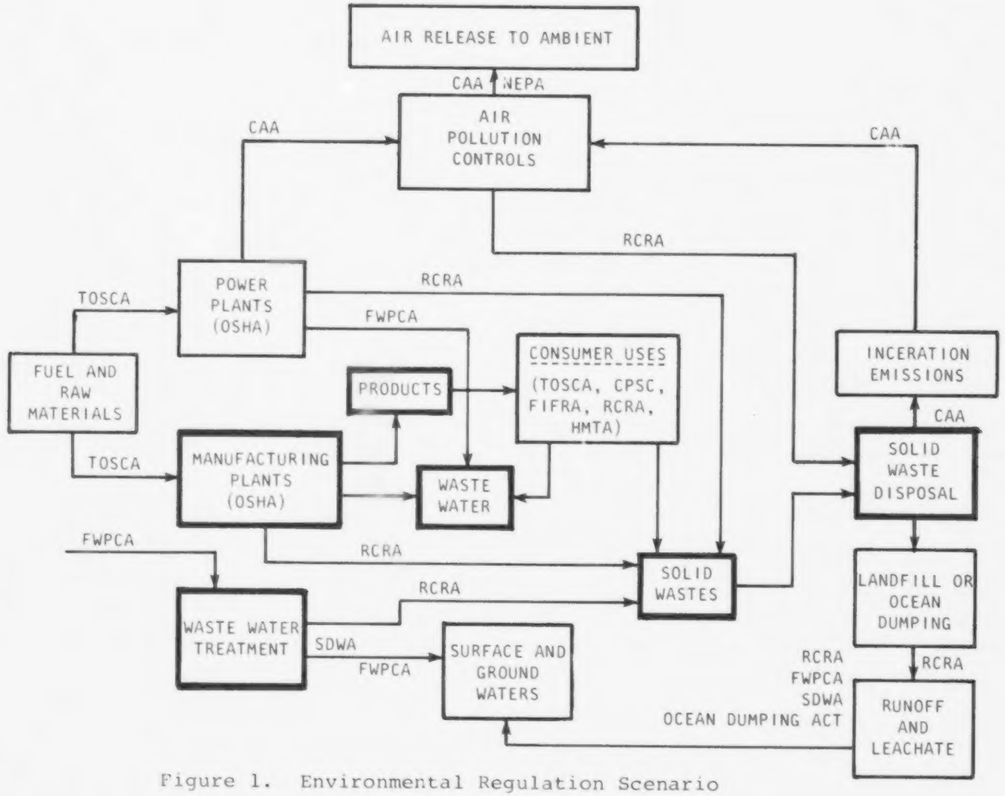

Figure 1. Environmental Regulation Scenario

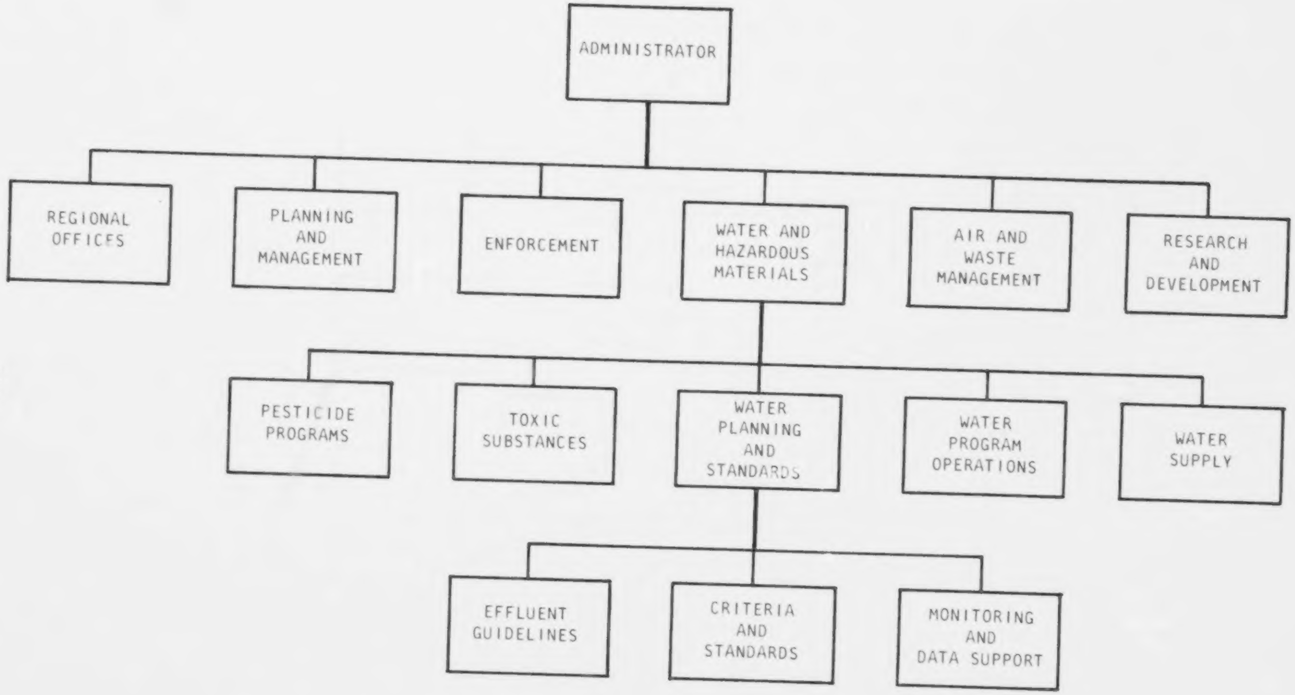

Figure 2. United States Environmental Protection Agency

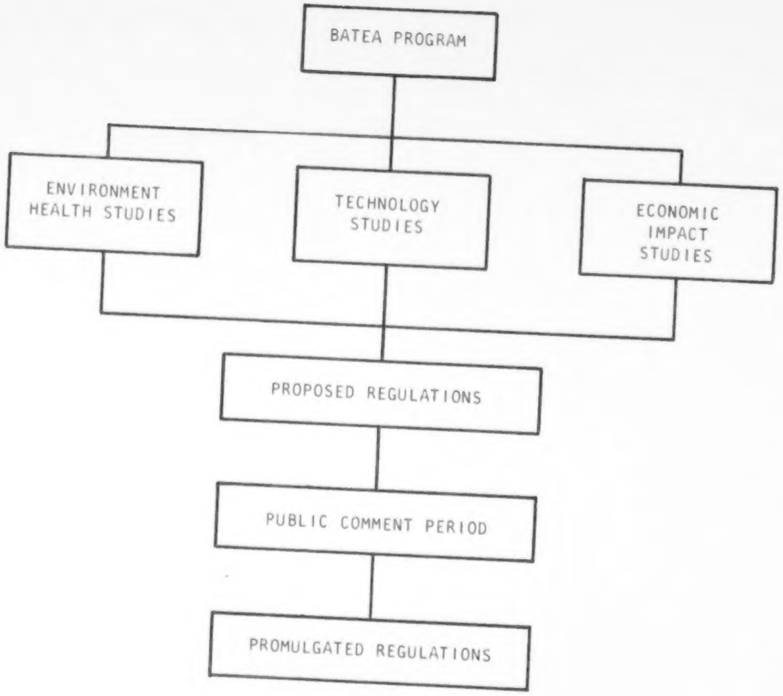

Figure 3. Primary Industries Regulation Development

REUSE OF RECLAIMED FRUIT PROCESSING WASTEWATER[1]

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Snokist Growers, a producer-owned cooperative of Yakima, Washington, conducted a two-year evaluation of the technical and economic feasibility of reclaiming biologically treated fruit processing effluent for reuse in the cannery. The study was extended over the 1975 and 1976 fruit processing seasons which began each year in August and was terminated in approximately May of the following year. The investigations showed that processing wastewater reclamation and reuse is a feasible means for supplementing the fruit cannery water supply and significantly reducing its emission of wastewater and pollutants.

OBJECTIVES

The objective of the wastewater reuse investigations at Snokist Growers was to determine the feasibility of reclaiming biologically treated wastewater for: 1) equipment cleaning; 2) product cleaning and conveying; 3) direct contact container cooling and; 4) boiler feed to produce steam for cleaning, exhausting, cooking and blanching. An additional objective was documentation of the reduction of pollutants discuarged from the system by reuse of the treated wastewater and evaluation of the economics of wastewater reuse for achieving EPA best available technology effluent guidelines.

A Technical Advisory Committee was formed consisting of representatives from the U.S. Department of Agriculture Food Safety and Quality Service; the Food and Drug Administration Division of Food Technology; the Environmental Protection Agency Health Effects Research Laboratory; the Environmental Protection Agency Industrial Environmental Research Laboratory; and the National Food Processors Association, Western Research Laboratory. These technical representatives were gathered to provide input to the Work Plan and comment on the project results in order to assure they met the objectives of the various entities and responded to the concerns of the regulatory as well as industry people who could influence future implementation.

BACKGROUND

Water Quality Requirements

Since Snokist Growers processes high acid foods packaged in hermetically sealed containers and contracts for continuous USDA product grading services, specific requirements for water quality are based on the Food and Drug Administration (FDA) "umbrella GMPs."[1] Those GMPs state that the water supply should be sufficient for the operations intended and shall be derived from an adequate source. Any water that contacts food or food contact services shall be safe and of adequate sanitary quality. It further states that water used for washing, rinsing or conveying of food products shall be of adequate quality and water shall not be reused for washing, rinsing or conveying products in a manner that may result in contamination of food products. The definition of adequate indicates that it is what is needed to accomplish the intended purpose in keeping with good public health practice.

The USDA continuous inspection program has requirements that "the water shall be of safe and sanitary quality with adequate facility for its protection against contamination and pollution."[2] It was understood during this project that the purpose of the requirements of the FDA and USDA were to prohibit the introduction of adulterated food into interstate commerce and that the food shall be deemed adulterated if it consists of any filthy, putrid or decomposed substance or if it has been packed under insanitary conditions whereby it may have been contaminated with filth or whereby it may have been rendered injurious to health according to FDA and USDA definitions. It was apparent that any project involving reuse of the renovated wastewater must address product safety and quality, plant sanitation as well as renovated water quality and reclamation system reliability.

Previous studies of effluent reuse in food processing plants have been carried out at a poultry processing operation[3] and a potato processing plant.[4] In the poultry processing wastewater reuse study it was concluded to be economically feasible to treat the wastewater to a level complying with the biological, chemical and physical limits of the U.S. primary drinking water regulations; however, in subsequent negotiations it was found that the USDA requirement for use of "potable" water was in conflict with EPA's definition of the term. Therefore, the reuse of poultry processing effluent in the processing plant has not been implemented. The study of reuse in a potato processing plant was conducted with the renovated wastewater used in the peelers, scrubbers and washers and for fluming trim table wastes; however, no data was collected or presented on the physical, chemical or microbiological quality of the reclaimed water except that proper chlorination apparently effectively controlled or eliminated the salmonella, staphylococcus and E Coli. It was reported that the economic feasibility was positive although the facility has since been shut down and the operation discontinued.

Facilities

Snokist Growers' cannery processes approximately 250 metric tons (kkg) of pears per day for about two months, about 250 kkg of peaches per day for about one week and 100 to 150 kkg of apples per day for two to four months during a typical processing season. The processing wastewaters are normally treated by biological treatment facilities (activated sludge) constructed in 1967 and 1968. Table 1 contains a description of the facilities and the design capacity of the treatment system. This system was effective in reducing BOC and suspended solids levels in the processing effluent on a consistent basis and was described adequately for a considerable amount of implementation of similar systems at various processing plants.[5,6,7]

Snokist Growers' cannery wastewater treatment system was selected as being exemplary during the development of guidelines for best practicable technology for wastewater treatment according to provisions in the Federal Water Quality Amendments of 1972 (Public Law 92-500).[8]

TABLE 1. EXISTING 1974 SNOKIST GROWERS PROCESS WASTEWATER TREATMENT FACILITIES

Facility	Description
1. Screening	8 mesh/cm (20 mesh/in) vibrating screens.
2. Aeration Basin	22,700 cubic meter (6 million gallon) earthen dike, PVC lined basin with 5 surface aerators having a total of 292 kw (390 horsepower).
3. Clarifier	27.5 meter (90 ft.) diameter, hydraulic sludge removal, 2.4 m (8 ft.) side water depth, center feed.
4. Sludge Recirculation	Two variable speed pumps each with 6,600 liter per minute (1750 gal. per minute) capacity.
5. Sludge Reaeration	5,700 cu. meter (1.5 million gal.) basin with 45 k2 (60 horsepower) surface aeration.
6. Sludge Thickener	9.2 meter (30 ft.) diameter pressurized recycle flotation sludge thickener.

Design Capacity of Biological Treatment System
Flow = 6.8×10^6 liters/day (1.8 mgd)
COD = 10,000 kg/day (22,000 lb/day)
BOD = 7,300 kg/day (16,000 lb/day)

Prior to the initiation of the reclamation and reuse study additional facilities were added as described in Table 2. Figure 1 shows the schematic flow diagram for Snokist Growers' wastewater treatment and reclamation system. Internal cannery piping was also added prior to the reclamation and reuse investigations so that reclaimed water could be delivered to various reuse locations within the cannery separately from the house water supply. Thus, the normal house water supply and the reclaimed water would not be mised in any portions of the cannery.

TABLE 2. TREATED WASTEWATER RECLAMATION FACILITIES

Facility	Description
1. Filters	Two 2.4 meter (8 ft.) diameter by 1.8 meter (6 ft.) high pressure filters. Area = 4.7 sq. meters (50 sq. ft.) each. Media = Microfloc MF 177 - 91.5 cm (36 in.) depth: 30% 1.5 sp.gr. anthracite (3 mm); 30% 1.6 sp.gr. anthracite; 30% 2.6 sp.gr. silica sand; 10% 4.0 sp.gr. garnet sand (0.25 mm) supported on 7.6 cm (3 in.) 1-2 mm 4.0 sp.gr. sand and 28 cm (11 in.) graded silica gravel. Pipe underdrain, surface wash, pneumatically operated automatic valves, automatic backwash and automatic flow control.
2. Filter and Backwash Pumps	Two constant speed pumps each with 3800 liter (1000 gal.) per min. capacity.
3. Reclaimed Water Pump	Split case 2600 liter (700 gal.) per min.
4. Chlorinator	One 227 kg (500 lb.) per day chlorinator, "compound loop" control.
5. Chlorine Residual Analyzers	Two wastewater type amperometric continuous flow analyzers.
6. Chlorine Contact Chamber and Backwash Water Storage	Two hundred twenty seven cu. meter (60,000 gal.) baffled chamber.
7. Controls and Operation	a. Flow to filters automatically maintained according to chlorine contact level up to a preset maximum rate per filter. b. Filter backwash initiated by timer, high head loss across filters or manually.

(Continued)

TABLE 2. (Continued)

Facility	Description
	c. Chlorine residual automatically maintained by flow proportioning and residual monitoring and feed rate adjustment.
	d. Chemical feed of alum and/or polymers, if used, paced to filter flow rate.
	e. Reuse pump automatic shutdown at low contact tank level.
	f. Alarms transmitted to wastewater lab and plant for appropriate action due to the following:
	1) Low or high chlorine residual in reclaimed water.
	2) High turbidity in filtered water.
	3) Low contact level.
	4) Filter system malfunction.

Design Capacity of Reclamation System = 3 x 10^6 liters/day (0.8 mgd)

PROCEDURES

Fruit processing at Snokist Growers' cannery consists of bringing the fresh or stored fruit to the cannery in bins where it is dumped in water and water conveyed (initial washing) to dry conveyor belts to the peeling areas. The fruit is mechanically peeled with the exception of peaches which undergo lye peeling. The peeled fruit is washed, inspected and cut into the proper size. Pears and peaches following final inspection are placed into containers, the containers are filled with syrup and enter the thermal processing line. The thermal processing consists of exhausting by live steam to preheat the canned contents and strip all oxygen from the contents prior to placing of the lid on the can, continuous retorting and direct contact cooling with water by sprays and submersion. Plums are similarly processed except they are not peeled. Apples are processed into applesauce or apple slices. Applesauce is finished then continuously cooked by live steam injection in a scroll cooker ahead of can filling, lid placement on the cans and direct contact container cooling. The apple slices are blanched by live steam injection in a continuous scroll blancher prior to can filling, placement of lids on the cans

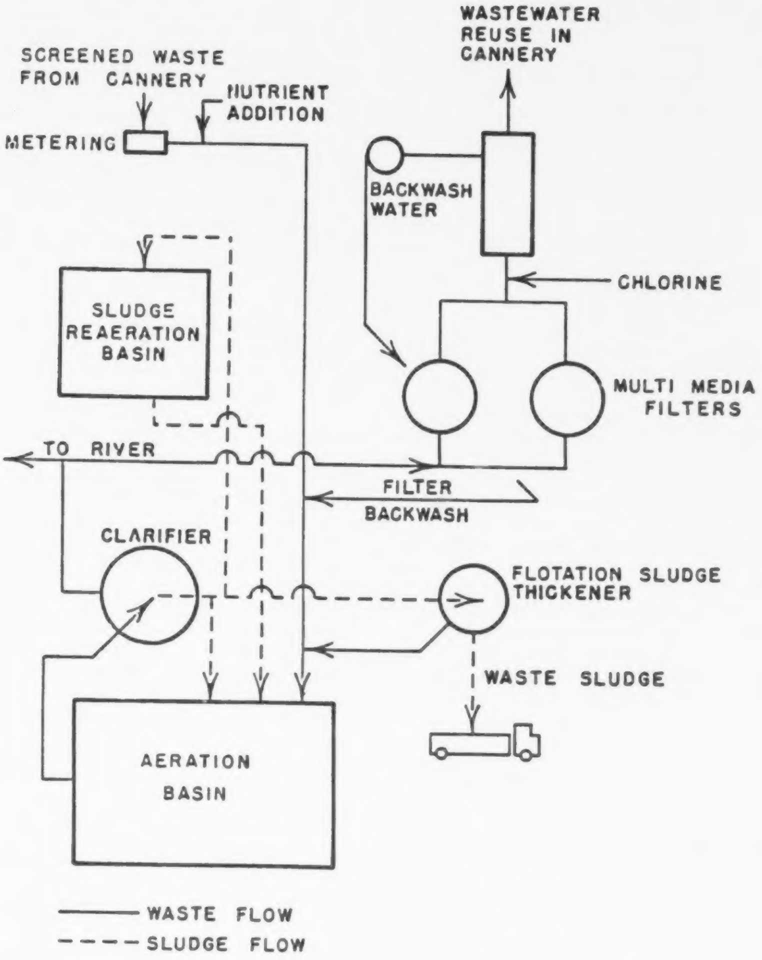


Figure 1. Snokist Growers' cannery processing wastewater treatment and reclamation system schematic flow diagram.

and direct contact container cooling. Apples are also packed in glass containers as applesauce and apple rings. Applesauce is finished and placed into the glass containers and cooled by water sprays. The apple rings are placed in glass and cooked in batch retorts before water spray cooling.

All of the processing wastewater at the Snokist cannery goes through the treatment system described above (sanitary wastewater is excluded from the processing wastewater system). Following screening, nutrients (nitrogen and phosphorous) are added in the proper proportions (BOD:N:P approximately 100:4:0.8) ahead of biological treatment. The activated sludge biological treatment system consists of the aeration basin, clarifier and sludge recirculation system. Detention time in the system ranges from 3 to 6 days depending on the product being processed. Sludge recirculation rate is maintained at from 1 to 1.5 times the waste flow rate. The nutrient feed is adjusted according to the nitrogen and phosphorous levels in the clarified effluent which are maintained between 0.5 and 1.0 mg/l.

Treated wastewater for reclamation is withdrawn from the clarifier effluent ahead of the outfall to the Yakima River. The clarified effluent is pumped through the two pressure filters which discharge to the chlorine contact basin. The filter rate is automatically varied according to demand as measured by the chlorine contact tank level. The chlorine contact tank also serves as an equalization tank and storage for filter backwash and for reuse in the cannery. A reuse pump withdraws water from the chlorine contact and discharges it through a pressure system into the cannery which is separate from the normal cannery house water supply. Alum can be added ahead of the pressure filters and during this investigation was varied in dose. The dose rate is automatically proportioned to the flow. The chlorination system also automatically proportions to the flow and has a residual analyzer system to override the proportioning system and maintain a continuous chlorine content. The dosage and chlorine residual were also varied during the investigations to assess disinfection requirements. Backwash from the filters was discharged to the aeration basin. Activated sludge system waste sludge was thickened by dissolved air flotation and disposed of on land.

Analytical procedures during the study were agreed to by FDA, EPA, USDA and the project investigators. Most of the analyses were performed at the laboratory at Snokist Growers Cannery and included chemical tests, COD, BOD, suspended solids and bacteriological analyses. Bacteriological procedures for total plate count, coliform, fecal coliform, staphylococcus, salmonella, mold, yeast and aerobic mesophylic spores were coordinated with the EPA Corvallis laboratory and the NFPA Western Research Laboratory. Pesticides were run by EPA Region X Laboratory as were the polychlorinated biphenyls (PCBs). Herbicides used in the orchards or storage areas of Snokist Growers' fruit sources were analyzed by the Columbia Laboratories, Inc. in Corbett, Oregon. Halogenated organics analyses were performed by the EPA Region X Laboratory and by Foremost Foods Laboratories in Dublin, California. Specific analyses and their frequency were according to the agreed upon schedule which is presented in the final project report.[9]

Reuse trials for the reclaimed water were also according to agreed upon procedures by the technical advisory committee[9] and will be summarized in the results discussion. Reclaimed water delivery to the cannery was in a separate piping system from the house water supply in order that the wastewater reuse areas could be isolated and tested during the pilot runs. Steam was generated from the reclaimed water by a portable steam generator. Analysis of the canned products for comparison between processing using the reclaimed water and the house water supply was done at the National Food Processors Laboratory in Berkeley, California.

WASTEWATER RECLAMATION RESULTS

The reclamation and reuse studies were conducted during the 1975 and 1976 processing seasons and performance data on wastewater emission rates and on the biological treatment system were collected for the 1974 season for comparison. Table 3 contains the flow rate per unit of raw fruit processed over the three seasons and the typical wastewater strength for each of the products. Variations in wastewater strength occurred during pear processing when the 1976 season processing procedure included recovery of peel and core waste from the peeler machines into bins for separate hauling for disposal as cattle feed which reduced the waste strength by approximately 1/3. The raw wastewater was very nutrient deficient for biological treatment with nitrogen and phosphorous to BOD ratios of only approximately .004 and .006 respectively.

TABLE 3 RAW WASTEWATER AVERAGE CHARACTERISTICS

Fruit Processed	Flow cu. m/kkg fruit processed	COD mg/l	BOD mg/l
Pears	17	2500*	1800*
Peaches	36	2200	1600
Plums	32	700	550
Apples	22	1000	700

* Average COD and BOD concentrations during 1976 pear processing were reduced to 1400 and 1000 mg/l respectively by dry separate peel and core solids removal.

Biological Treatment

The biological treatment system included a complete mixed activated sludge aeration basin operated at a COD removal rate of approximately .04 to .25 grams removed per gram of mixed liquor volatile suspended solids (MLVSS) depending on the biological treatment. Effluent quality for conventional pollutants was monitored over the three processing seasons 1974 - 1976. The soluble COD was consistently less than 40 mg/l during the three seasons and less than 30 mg/l when aeration basin temperatures were 10^{o} C or greater. Soluble BOD concentrations were less than 10 mg/l consistently throughout the seasons. The total COD and BOD concentrations were highly dependent upon the suspended solids level in the biological effluent seemed to be a function of in-plant practices. During the 1974 season the biological treatment effluent suspended solids through peach, pear and plum processing including concurrent apple and pear processing during the last portion of pear season averaged 19 mg/l. During the 1975 process season, when a greater amount of in-plant chlorine usage to control geotrichium mold on machinery was practiced, the suspended solids in the biological effluent through the end of pear processing averaged 40 mg/l. During 1976 chlorination was still practiced but careful in-plant monitoring of the use of dry chlorine on belts and machinery surfaces was initiated and the suspended solids in the biological effluent averaged 15 mg/l through the end of pear processing.

Later during the 1976 season, however, the suspended solids concentration in the effluent deteriorated which could have been a result of either chlorine usage or cold weather or both. At one point in the 1976 pear processing season just following the Labor Day shutdown it was confirmed that waste toxicity affected the effluent suspended solids levels when a near complete upset of the biological system occurred following the first flush of clean water after the three-day shutdown.

Biological Effluent Reclamation

Biologically treated effluent was polished by mixed-media pressure filtration (Figure 4) and disinfected with chlorine to produce a reclaimed water for reuse in the cannery. Equipment malfunctions in the backwash automatic valve control system and in the chlorine control system during the 1975 season resulted in some periods of unsatisfactory operation of the reclamation system. During other portions of the season, however, satisfactory operation seemed to take place. During the 1976 season the equipment operated consistently. Feed rates of alum to the filter system and chlorine to the filtered effluent were varied in order to determine the effectiveness of these chemicals on reclaimed water quality.

Figure 5 shows the suspended solids concentration distribution in the biological effluent over the three processing seasons and in the filtered effluent during the 1975 and 1976 seasons. The filtered effluent suspended solids levels were a function of the suspended solids concentration in the filter feed (biological effluent). During both 1975 and 1976 there were periods when the filtered effluent suspended solids level exceeded that of the biological effluent. Table 4 shows the suspended solids removal for various periods during the 1975 and 1976 seasons. It also shows the alum feed rate. The period in 1976 in which the effluent suspend solids level exceeded that of the filter feed water was during the period when alum was fed and the concentrations varied indicating it was relatively ineffective at improving the filter performance. The period in 1975 when the filter showed a net increase in solids were for short durations during periods of equipment malfunction so that alum feed could not be attributed to the increase at that time.

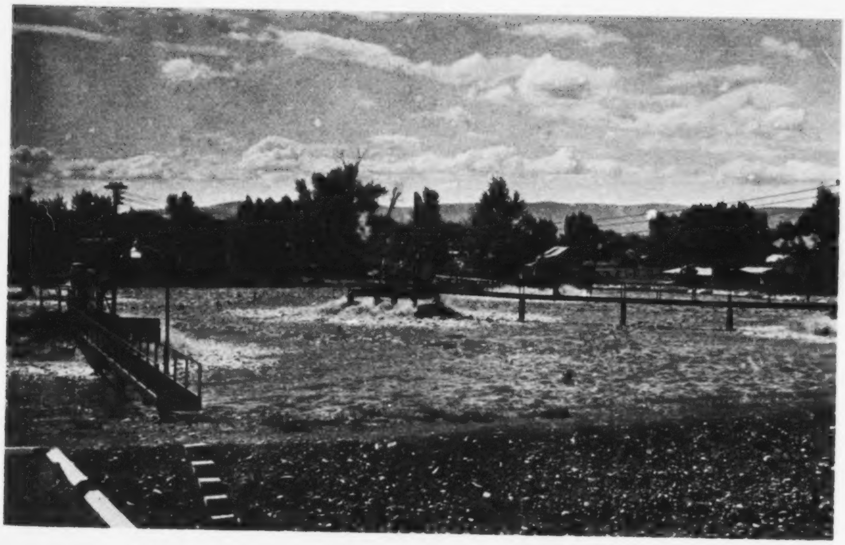


Figure 2. Activated sludge system areation basin.

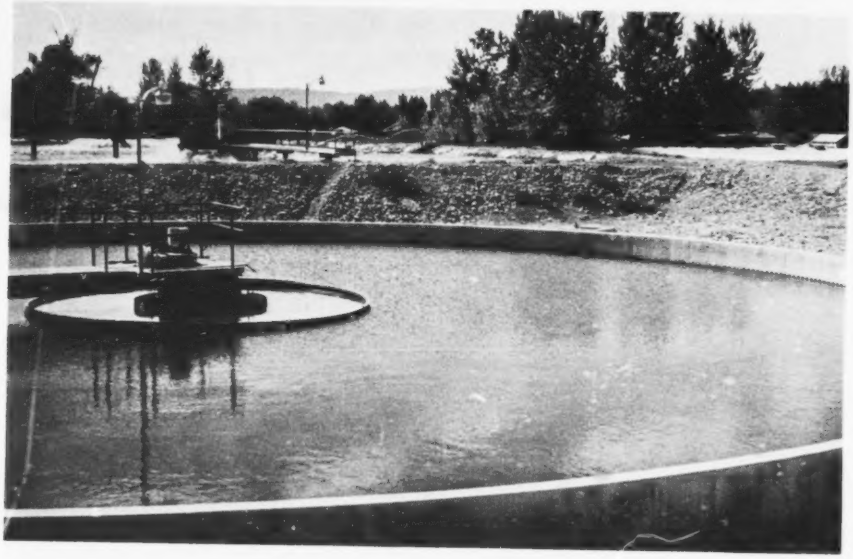


Figure 3. Activated sludge system clarifier.

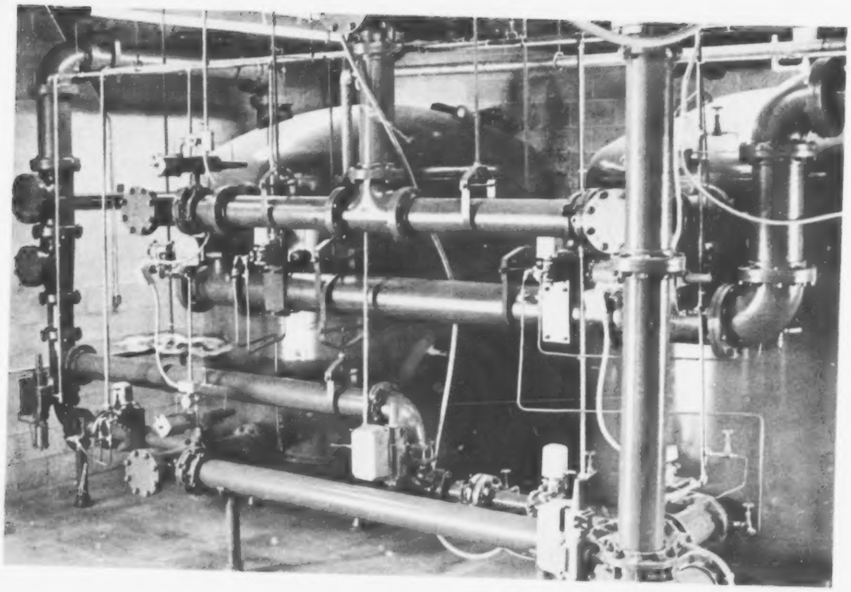


Figure 4. Wastewater reclamation system multimedia pressure filters.

TABLE 4. MIXED MEDIA FILTER SUSPENDED SOLIDS REMOVAL

Processing Season & Dates	No. of* Test Days	Suspended Solids Mean mg/l ± Std.Dev. Biological Effluent	Suspended Solids Mean mg/l ± Std.Dev. Filter Effluent	Suspended Solids Removal Mean ± Standard Deviation mg/l	Suspended Solids Removal Mean ± Standard Deviation %
1975					
8/12-10/4	29	25 ± 8	17 ± 8	8 ± 4	33 ± 18
10/6-10/23	14	92 ± 46	85 ± 42	7 ± 11	8 ± 10
10/24-11/19	21	19 ± 7	15 ± 6	4 ± 3	20 ± 16
11/20-11/24	3	14 ± 7	9 ± 1	5 ± 7	22 ± 35
12/1-12/9	7	80 ± 14	70 ± 11	9 ± 7	11 ± 7
12/10-12/18	7	42 ± 12	34 ± 10	8 ± 5	18 ± 9
1976					
8/24-9/4, 9/13-10/2	28	8.2 ± 2.6	5.6 ± 2.4	2.6 ± 3.2	26 ± 44
9/7-9/11	5	56 ± 28	42 ± 22	14 ± 8	27 ± 15
10/4-11/4	27	13 ± 4	9 ± 4	4.0 ± 2.2	31 ± 14
11/5-11/13	7	18 ± 4	29 ± 5	-11 ± 8	-70 ± 62
11/15-11/23	7	16 ± 5	30 ± 13	-14 ± 10	-85 ± 53
11/29-12/3	5	52 ± 9	121 ± 36	-69 ± 32	-134 ± 65
12/6-1/7	21	32 ± 12	23 ± 15	9 ± 6	33 ± 21
1/19-1/31	9	78 ± 19	56 ± 18	22 ± 11	29 ± 11
2/23-3/10	12	79 ± 40	77 ± 38	2 ± 8	3 ± 10

* Alum added

Season	Dates	mg/l	Season	Dates	mg/l
1975	10/8-15, 11/5-8	Approx. 15	1976	11/10-12/1	22
	11/11-14, 17-20	30		12/2-4	45
	12/2-5, 8-12, 15-19	30		12/6-1/19	30
1976	10/1-7, 15-19	15		1/20	45
	10/7-14, 20-11/9	20		1/21-3/10	15

* Filter rate - maximum set at 1400 liter/min. ea. (0.5 cm/sec.)

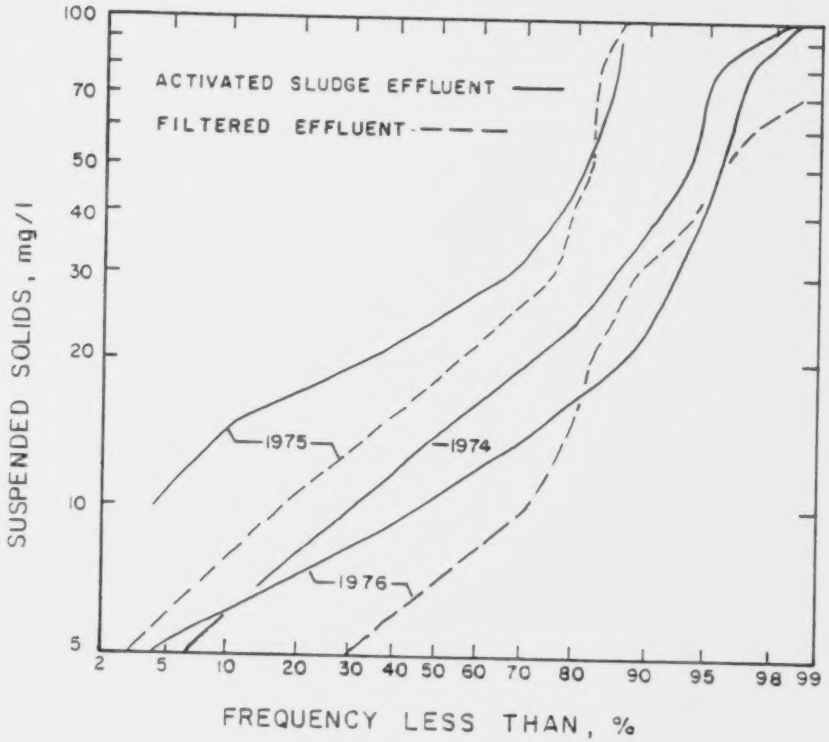


Figure 5. Suspended solids concentration frequency in the biological treatment and multi-media filter effluents.

Periods of comparable suspended solids concentration in the feed to the filters were compared statistically when alum was and was not added. There were no differences in suspended solids removal by the filters at various alum dosages up to 30 mg/l. The filters were as effective at removing suspended solids without alum addition as when alum was added at feed concentrations up to 30 mg/l. It was apparent from these investigations that in order to provide a high clarity reclaimed water for reuse that the biological treatment effluent clarity was of paramount importance. Thus the biological system must be operating properly and the clarification must be adequate ahead of the mixed-media filters in order to prevent high suspended solids from passing through the filters into the reclaimed water system. The filter system consistently removed only about 30% of the suspended solids applied.

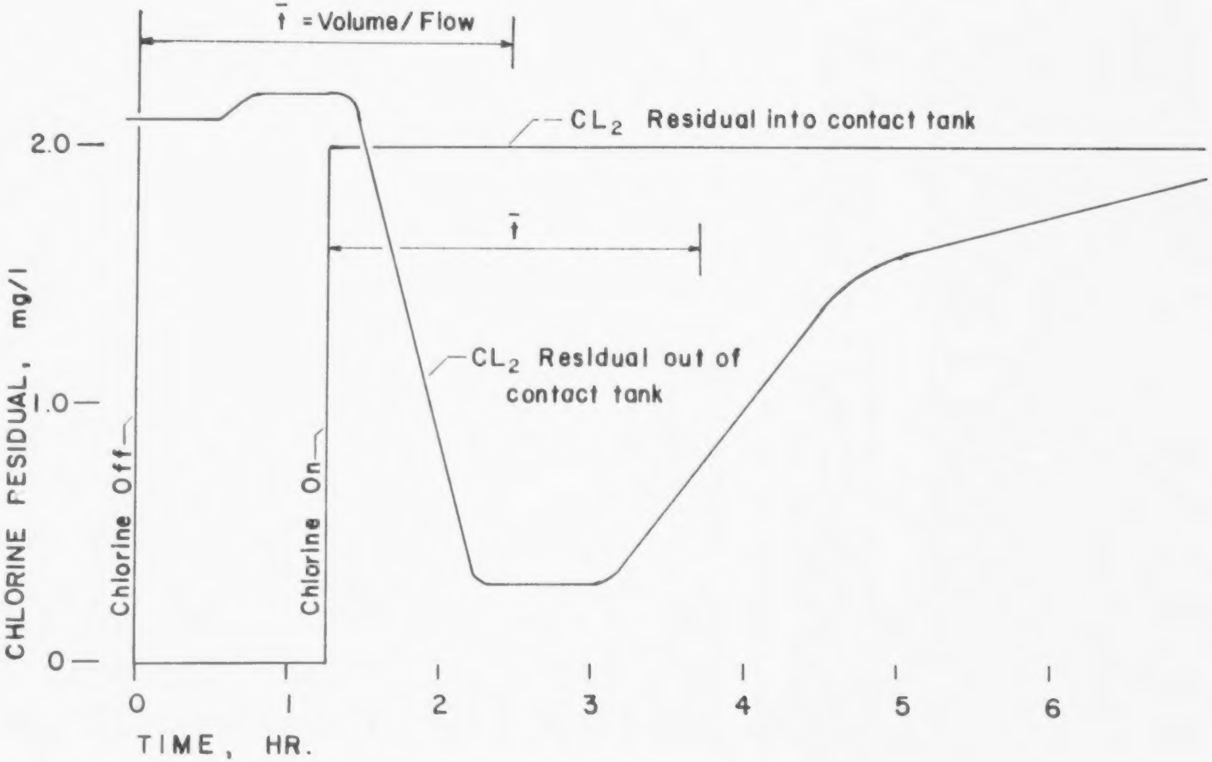
The BOD and COD levels of the reclaimed effluent averaged less than 10 mg/l and less than 40 mg/l except when high suspended solids were escaping from the filtration system. At that time the COD increased proportional to the suspended solids in the reclaimed water.

Disinfection of Reclaimed Wastewater

Disinfection is a function of the initial mixing of the chlorine solution with the filtered water (injected through a diffuser across a 20 cm pipe), chlorine residual concentration and contact time. The contact should be under plug flow conditions. The chlorinated filtered water entered the contact tank at one end and was withdrawn from the opposite corner. Six baffles forced the water to travel the width of the tank seven times prior to withdrawal. Figure 6 shows the results of tests for chlorine residual in the contact basin influent and effluent when the chlorine feed was turned off for approximately 1/2 of a detention time. The resulting chlorine residual at the tank discharge indicates that the tank provided a reasonably good approximation of plug flow at the 1500 liter per minute feed rate during the test.

Disinfection efficiency and consistency relies on the maintenance of a consistent chlorine residual in the wastewater and through the chlorine contact facility. During the 1975 operating season the chlorine residual analyzer units clogged occasionally due to the high suspended solids carry over, which caused fluctuations in the chlorine feed rate. The better reclaimed effluent suspended solids concentrations achieved during the 1976 season, accompanied by improved operation and maintenance of the equipment, resulted in more stable and consistent chlorination results. The chlorine residual measured by the two automatic analyzers (with periodic manual checks) as total chlorine residual. Since the ammonia content of the biological effluent was always near zero the residual was usually as free chlorine.

The bacteriological quality of the cannery house water, processing effluent and treated effluent prior to chlorination are shown on Table 5. Even though there was no sanitary waste in the processing effluent stream there was a substantial coliform count due to soil bacteria entering the waste stream in the processing area from fruit washing and from floor runoff. There were bacteria responding to the high temperature fecal coliform test in the waste stream but in numbers approximately three orders of magnitude less than the total coliform counts.



6. Chlorine contact tank flow-through characteristics.

Figure 7 shows the coliform counts following disinfection of the reclaimed effluent plotted against chlorine residual in the chlorine contact tank over the two seasons. This figure indicates that a 3 mg/l chlorine residual was adequate to assure very low levels of coliform bacteria in the reclaimed effluent. No positive coliform counts were obtained when chlorine residuals were 3 mg/l or greater. The three high effluent coliform counts shown for the 1975 processing season occurred during the time when chlorine residual analyzer problems may have caused fluctuations in the residual chlorine level.

The level of total bacterial content was assessed by use of the total plate count. The total plate count in the reclaimed effluent is shown on Figure 8 plotted against chlorine residual in the chlorine contact tank. Once again it is evident that maintenance of the chlorine residual of 3 mg/l or greater provided a marked improvement in the bacteriological quality. At chlorine residuals of 3 mg/l or greater the chlorine contact effluent, bacterial content was consistently less than 500 organisms per milliliter.

Positive reactions to the fecal coliform test were not observed in renovated wastewater as long as the chlorine residual in the contact tank was adequate for a consistent positive reading. No staphylococcus or salmonella group organisms were isolated in the renovated wastewater throughout the two-year study.

Yeast, mold and mesophilic spores were quantified in the reclaimed wastewater during the 1976 processing season. These results are shown on Figure 9 plotted against chlorine residual. The data analysis indicates that low levels of these organisms were present in the filter effluent. It also indicates that a chlorine residual level of about 3 mg/l reduced these indicators of sanitory quality to insignificant levels.

With the exception of the one-week period in September when biological upset occurred, the 1976 season coliform bacteria and total plate count relationships with chlorine residual were consistently maintained. No positive coliform results and no total plate count results over 500 per ml were obtained at chlorine residual of 3 mg/l or more up through turbidity levels of 30 NTU.

Turbidity Removal from Reclaimed Effluent

The reclaimed effluent turbidity was measured in nephelometric turbidity units (NTU) using a continuous flow turbidity cell. Grab samples were measured for turbidity using a bench scale unit. The two units did not correspond in turbidity readings since the bench model measured forward scatter turbidity whereas the continuous flow unit measured side scatter turbidity. The reading from the two units did correlate, however, over the low level range available on the side scatter unit. The log mean ratio of the continuous reading turbidity values (NTU) to the reading obtained from the bench turbidimeter was 0.35 (95% confidence range, 0.20 to 0.60). There was no significant difference between the ratios during portions of the processing season in 1976 and the ratio was the same with or without alum feed to the filters. Side scatter turbidity measurements in NTU are according to Standard Methods procedures while the forward scatter turbidity reading does not reflect Standard Methods procedures.

During the 1976 season, the turbidity of 74% of the operating days

TABLE 5 WASTEWATER AND WATER SUPPLY

BACTERIOLOGICAL QUALITY

Sample Point		Total Coliform per 100 ml	Total Plate Count per ml
Cannery Water Supply (unchlorinated)	Log Mean	1	1.5
	95% Confidence[1]	No positive results	.003 to 870
	no. samples[2]	22	14
Process Wastewater[3]	Log Mean	4.0×10^5	75,000
	95% Confidence	1,300 to 1.3×10^8	8,800 to 6.3×10^5
	no. samples	38	31
Biological Effluent	Log Mean	4.1×10^5	33,000
	95% Confidence	17,000 to 9.8×10^6	1,200 to 9.5×10^5
	no. samples	195	158
Filtered Effluent (unchlorinated)	Log Mean	2.8×10^5	24,000
	95% Confidence	7,100 to 1.1×10^7	370 to 1.0×10^6
	no. samples	195	154

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[1] Log Mean ± 2 Log Std. Deviations.
[2] During 1975 and 1976 Processing Seasons.
[3] No sanitary wastes can enter processing wastewater.

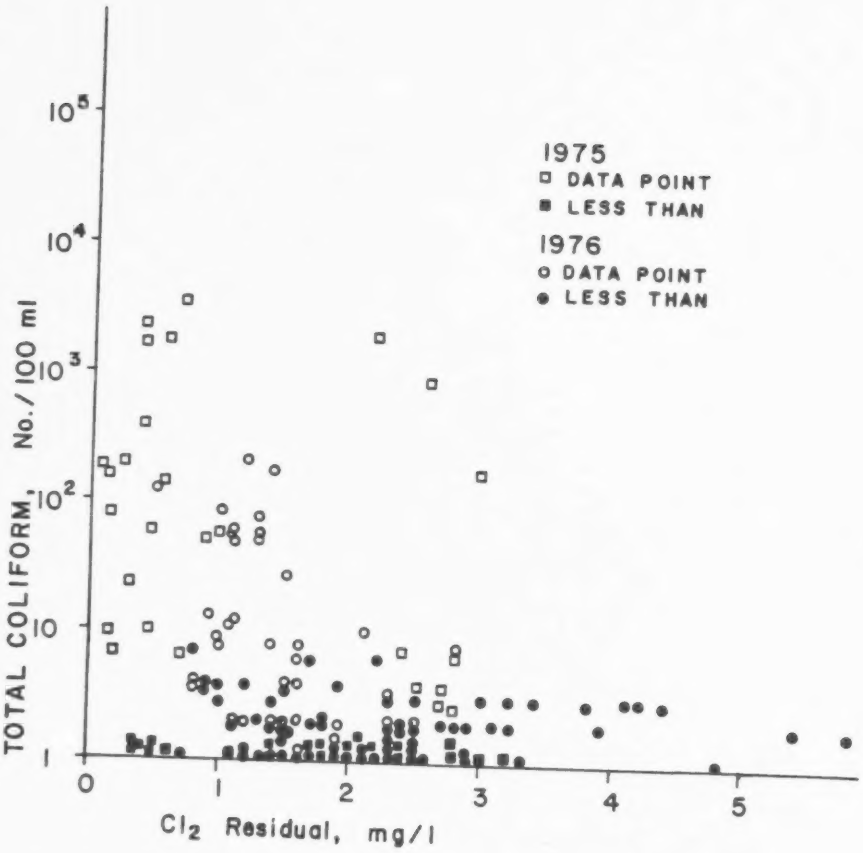

Figure 7. Reclaimed wastewater total coliform content vs. contact chlorine residual.

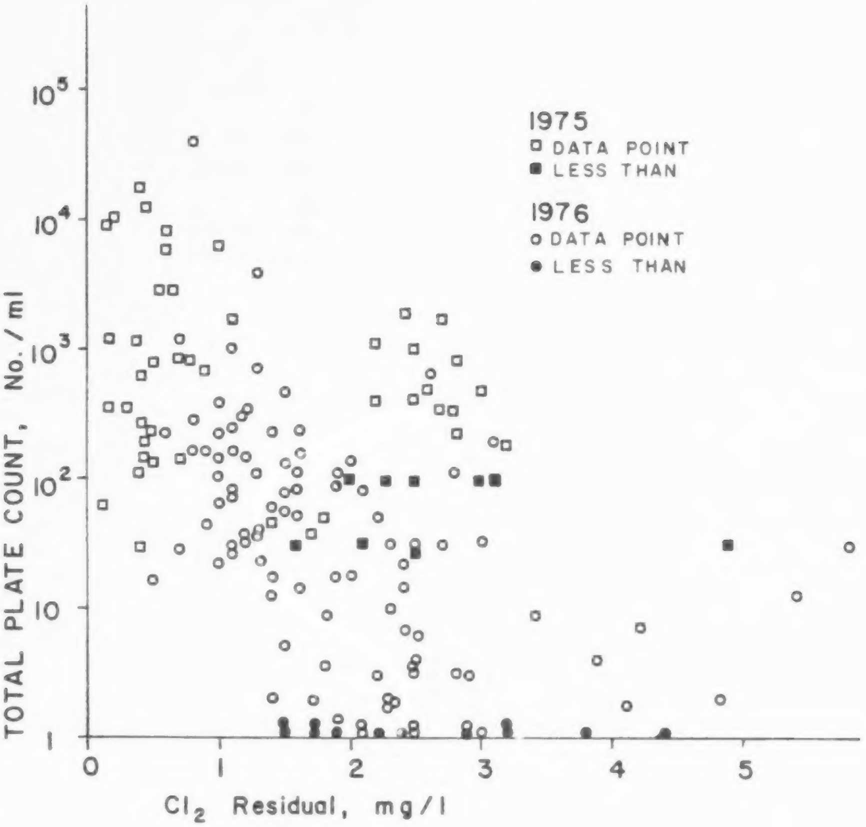

Figure 8. Reclaimed wastewater total plate count vs. contact chlorine residual.

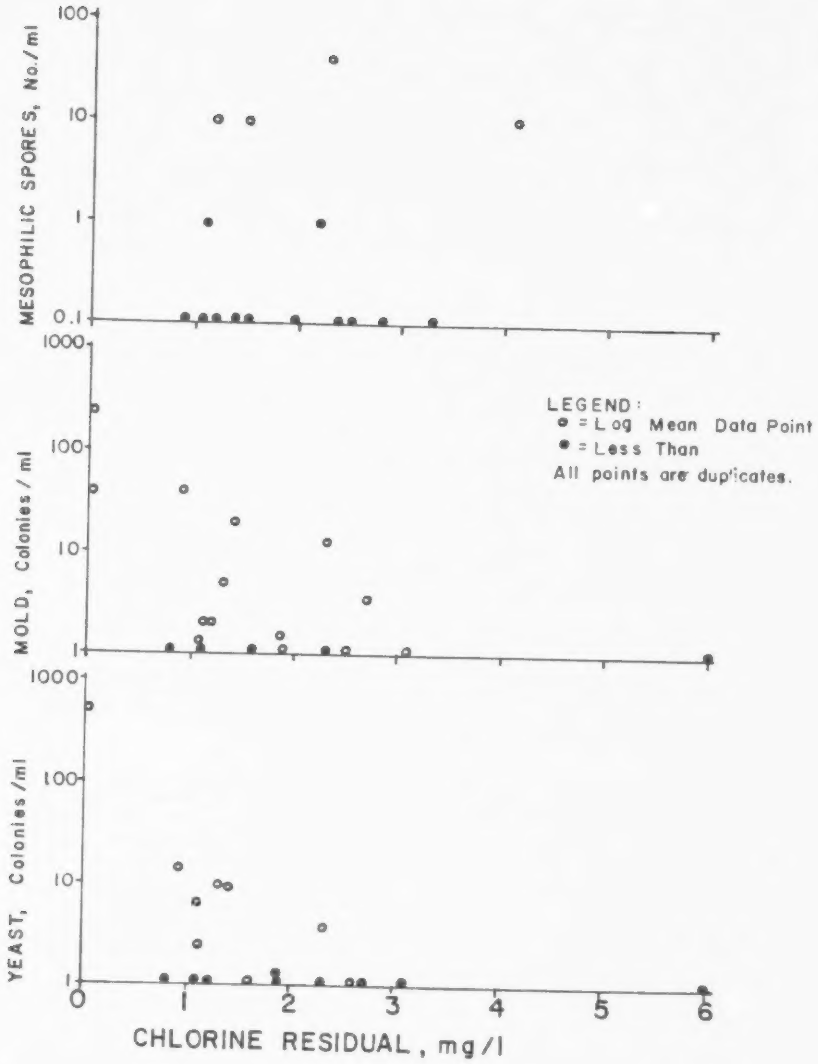

Figure 9. Yeast, mold and mesophilic spore count of reclaimed wastewater vs. chlorine residual.

was less than 10 NTU. The turbidity was less than 15 NTU on 80% of the days, less than 20 NTU on 85% of the days and less than 30 NTU 90% of the time. The 10% of the operating days when turbidities exceeded 30 NTU in the reclaimed water occurred during the one-week period in September when extreme biological upset was caused by an apparent toxic discharge from the cannery (assumed to be chlorine) and during the period following the onset of cold weather from the end of November through February. During a portion of the cold weather period the basin had a considerable ice cover which caused quality problems in the effluent. During the 1975 season excluding the one-week upset period and prior to the on-set of cold weather, turbidity measurements were less than 10 NTU during the entire operation.

Heavy Metals

Heavy metals analyses were run by National Food Processors Association Laboratories in Berkeley, California by Atomic Adsorption Spectrometry. The results of the testing for heavy metals are contained in Table 6. For the heavy metals with maximum concentration limitations (MCLs) under the Primary Drinking Water Regulations there were no analyses indicating that the tap water supply in the cannery exceeded the limitations. One reclaimed wastewater test exceeded the limitations for mercury (Hg) by a small amount. The date of the test was the same as for the highest mercury concentration level test result for cannery water supply. Each were over twice the maximum shown on any other date of analyses indicating a possibility that the analytical results were incorrect on that date.

Most heavy metals tests values were less than the detectable limit. The detectable limits were not consistent but were established with the atomic adsorption apparatus on each date of analysis. The values reported as less than (<) reflected sensitivity at the time of the test which accounts for the difference between the median and maximum concentrations reported in most of the samples.

The aluminum content in the reclaimed wastewater was below detectable limits for all samples except when alum was being fed ahead of the filters. The increase in sodium concentration between the tap water and the reclaimed effluent resulted primarily from sodium being retained in the system after the lye peeling period for peach processing. The same is true of potassium which was apparently contained in the caustic used for the peach peeling. The reduction in calcium and magnesium and between the tap water and reclaimed effluent samples probably resulted from calcium and magnesium precipitation during the high pH waste period of peach processing.

Pesticides

Analyses were run for all of the pesticides recommended for inclusion in the drinking water standards by the EPA advisory committee (with the exception of 2-4D) eight times over the reuse project. These chlorinated hydrocarbon pesticides are aldren, chlordane, DDT, Dieldrin, Endrin, Heptachlor Epoxide, Lindane, Methoxychlor and Toxaphene as well as 2,4,5-TP. Only Lindane, in a single sample, was found above the detectable concentration at .016 micrograms per liter (μg/l) which is well below the primary drinking water regulation level of four micrograms per liter. In addition to orchanochlorine pesti-

TABLE 6 HEAVY METALS RESULTS

Constituent	Std[1]	Cannery Water Supply[2]	Reclaimed Effluent[2]
Arsenic	.05	4 - < .01 - < .01	7 - < .01 - < .05
Cadmium	.01	6 - < .02 - < .03	9 - < .02 - < .03
Copper		6 - <.015 - < .05	9 - <.018 - < .05
Iron		6 - < .15 - < .25	9 - < .15 - < .25
Lead	.05	6 - < .01 - < .05	9 - .02 - < .05
Manganese		6 - < .01 - < .05	9 - <.025 - < .05
Mercury	.002	6 - .0003 - .0017	9 - .0003 - .0026
Tin		6 - < 1.0 - < 3.0	6 - < 1.0 - < 3.0
Zinc		5 - .015 - .02	9 - .28 - .50
Aluminum		3 - .10 - < .20	6 - < .10 - 2.2
Sodium		6 - 14 - 15	9 - 60 - 110
Potassium		6 - 2.9 - 3.0	9 - 15 - 17
Calcium		6 - 11.8 - 12.5	9 - 6.7 - 11.0
Magnesium		6 - 1.6 - 1.8	9 - 1.2 - 1.6

[1] Primary Drinking Water Regulations, mg/l

[2] Number of samples - median concentration, mg/l - maximum concentration, mg/l. Detectable limits for some heavy metals were different for different times of testing which accounts for differences between median and maximum values when each is less than (<) a value.

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cides, organophosphates were screened as parathion. Total organophosphate pesticides were below the 0.01 µg/l detectable limit.

Other pesticides known to have been applied to the fruit processed by Snokist or thought to be ubiquitous in nature were analyzed. These compounds were: BHC, DDD, DDE, Heptachlor, Perthane, Endosulfan, Sevin, Benomyl, Diphenylamine, Plictran, Karathane, Omite and Maneb. BHC was found at concentrations of 0.008 µg/l once in 1975 and at 0.28 µg/l in 1976. At the time of the 1976 positive reading BHC was also recorded to be present in the tap water at a concentration of 0.21 µg/l leading to suspicion of contamination of inconsistent laboratory procedures. Diphenylamine was detected in two samples with concentrations reported at 1 to 2 and 2 to 4 µg/l respectively. This compound was applied to the apples prior to storage for mold control so there was a potential source in the processing plant. However, the reported concentrations were also subject to uncertainty during analysis due to a difficulty in elimination of the blank from the analyzer.

The presence of polychlorinated biphenyls (PCBs) with molecular weights of 1242, 1248/1254 and 1260 was also monitored. Positive results were obtained for molecular weights 1248/1254 in the range from less than .01 to .065 µg/l; however, the material was detected at approximately the same concentrations in both the well water supply for the cannery and in the reclaimed effluent. It is not known whether the well water supply had a source of contamination. The results were erratic and the well water supply did not show a consistent level of the PCB in question leading to suspicion of the analytical procedures.

Organohalides

The reclaimed effluent was monitored for 6 organohalides throughout the 1976 processing season. A summary of the data by sampling date is presented in Table 7. The chlorine residual in total COD values for the renovated wastewater on those dates of organohalide analyses is also shown. Based on these dates no firm conclusions can be drawn regarding generation of trihalomethanes. The concentration of the total trihalomethanes observed were well below the EPA proposed regulation of 100 µg/l.

TABLE 7. ORGANOHALIDES IN THE RECLAIMED WASTEWATER,

1976 PROCESSING SEASON

	Sampling Date					
	9/21	10/21	11/16	12/14		3/8
1, 2-Dichloroethane (µg/l)	N.D.	N.D.	N.D.	N.D.[1]	N.D.	N.D.
Carbontetrachloride (µg/l)	1	1	1	N.D.	N.D.	1
Bromodichloromethane (µg/l)	1	1	1	N.D.	N.D.	1
Dibromochloromethane (µg/l)	2	1	1	1 to 3	1 to 3	1
Tribromomethane (µg/l)	N.D.	1	N.D.	N.D.	N.D.	1
Trichloromethane (µg/l)	8.2	5.8±0.6	24.8±2.3	1.5±0.2	1.6±0.2	13.4±
Total Trihalomethanes[2] (µg/l)	11	7	27	4		15
Chlorine Residual (mg/l)	2.9	1.2	3.3	1.6		1.5
COD (mg/l)	24	24	44	49		60

Notes: N.D. = Not Detected
1 = Duplicate samples
2 = Approximate sum of the 4 trihalomethanes

Effluent Reduction Resulting From Wastewater Reclamation Reuse

The reduction in effluent quantity resulting from effluent reclamation and reuse was 30% to 35% during the 1975 and 1976 seasons when the reclaimed effluent was used principally for nonsensitive cannery areas such as floor and gutter wash and washdown of areas not contacted by the peeled or final product. Wastewater average discharge rate was 20,200 liters/kkg in 1974 and was reduced to 14,000 liters/kkg in 1975 and 12,700 liters/kkg of raw fruit in 1976 processing season. It is anticipated that if the reclaimed water is used in direct contact container cooling and initial fruit washing and conveying on a continuous, full-scale basis that the overall effluent reduction would be approximately 50%.

Snokist Growers' treatment plant effluent has met EPA best practicable treatment (BPT) guideline levels for a number of years and their records were used in part to develop the best practicable guidelines. During peach and pear and combined pear and apple processing the effluent also met the guidelines for best available treatment (BAT). The effluent even with reclamation and reuse of about 30% of the effluent did not meet best available treatment for apple products during periods when apples were processed alone. In fact during apple processing without other products the unit mass emission rate for COD and BOD as well as suspended solids increased compared to what it was during the pear and peach processing. This was in part due to the fact that apples were processed at a much lower rate and were well below the designed capacity of the treatment system. Additionally, apple processing occurred during cold weather which seemed to result in lower effluent quality, and chlorine was used in the plant during portions of the apple processing season which tended to increase the suspended solids in the biological treatment effluent due to the chlorine toxicity.

Cost of Wastewater Reclamation

The capital cost of facilities for wastewater reclamation following biological treatment was approximately $325,000. This expenditure increased the cost of facilities for wastewater treatment at Snokist Growers' cannery since 1967 to approximately $800,000. The added operation and maintenance cost to reclaim approximately 220 million liters per year of wastewater is estimated at about $6,000. This is a cost of $.027 per 1,000 liters. Amortization of the $325,000 capital cost at 8% for 15 years raises the cost of the reclaimed water to about $.20 per 1,000 liters. The same amount of water provided each year assuming a new well were constructed would cost about $.085 per 1,000 liters. Therefore, the reclamation/reuse system is not economically justifiable at Snokist Growers based on the cost of the water alone; however, reclamation/reuse may be justified in order to achieve wasteload reduction requirements for future permits at Snokist and elsewhere. It would be economically justifiable in some cases where water costs are much higher than Snokist's groundwater withdrawal system.

RECLAIMED WATER USE

The reclaimed water was put to use during the 1975 and 1976 processing seasons for floor and gutter wash and washdown of other areas where the fruit did not come in contact with the washed surfaces. In addition the water was used in pilot investigations in other cannery areas. During the 1975 season pilot uses were investigated for equipment washing and direct contact container cooling. Pilot uses investigated in 1976 included equipment washdown, initial product cleaning and conveying, direct contact container cooling and boiler feed for steam generation. The generated steam was used for cleaning, exhausting, cooking and blanching.

Equipment Cleaning

During each the 1975 and 1976 processing seasons, parallel pear processing lines were cleaned using reclaimed or house water and comparatively tested for bacteriological count by a swab test procedure. Two sets of belts on each of the parallel lines was tested for bacteriological content. Table 8 contains the comparative results including the number of samples taken, the log mean and range of 1 log standard deviation around the mean of samples from each of the locations.

During 1975 the parallel lines were cleaned with a house water and house steam mixture for comparison to cleaning with a reclaimed water and house steam mixture on three occasions. The steam and water mixture was hot and the chlorine residual in the water portion was apparently helpful in disinfecting the lines. During the 1976 processing season three parallel lines were cleaned one day a week for six weeks using a house water and house steam mixture compared to a reclaimed water and house steam mixture and reclaimed water mixed with steam generated from the reclaimed water. The two belts tested on each processing line were the peeler belt and a shaker belt which carried the product away from those respective pieces of equipment. The equipment was recleaned using house water and house steam following the bacteriological monitoring for comparative purposes. During the 1976 processing season the chlorine residuals were more nearly the same and there was no significant difference between the results of cleaning the parallel lines.

Waste slide belts were constructed for the 1976 season for long term studies of the use of the reclaimed water for cleaning. These belts were used only for the transport of peel and cores from the mechanical peelers. They were washed each day using the various treatments of house and reclaimed water and steam and sampled twice a week for about six weeks. The belts were not rewashed with house water and house steam as were the processing belts. The data shown on Table 8 does not indicate that there was a buildup or a difference in the bacteriological quality between the various treatments.

Direct Contact Container Cooling

On one day during each the 1975 and 1976 processing seasons, contact container cooling with reclaimed water was performed on a trial basis using one of the coolers regularly used for cooling the thermally processed canned product. The cooler was filled with reclaimed water and brought up to normal cooler operating temperature with steam injection. All cans trial cooled in the reclaimed water were retained for testing and observation. An equal number of cans from the same cooler during the normal run that day were retained for comparison. During the 1975 season approximately 1200 cans of pears cooled in each of the two waters were retained for comparison and during the 1975 trial about 3,000 cans from each of the two waters were retained for comparison.

Approximately 100 cans from each of the two waters in each season were sent to National Food Processors Association Laboratory in Berkeley, California for accelerated storage trials. In 1975 they were incubated at 30° C for two months to simulate long-term storage. During 1976 they were incubated at 35° C for six months. Following the accelerated storage trial the cans were checked and there were no differences between the cans cooled in reclaimed water and those cooled in normal house water. There were no container failures due to swells or leaks during either of the years and there was no difference in vacuum of the cans. Containers were checked for spotting and corrosion externally and internally and there was no difference between cans from the two trial waters. The remainder of the 1000 cans in 1975 and the 3000 cans in 1976 from each of the trials were retained for one year and examined for failures. There were no swelled or leaking cans at the end of the period of storage at 18° C from either of the trials.

TABLE 8. SANITARY CONDITION OF PROCESSING EQUIPMENT CLEANED WITH VARIOUS COMBINATIONS OF WATER AND STEAM

Item	CLEANING TREATMENT Reclaimed Water Reclaimed Steam	 Reclaimed Water House Steam	 House Water House Steam
1975 PROCESSING SEASON			
Peeler & Shaker Belts		n = 12	n = 12
Log Mean Plate Count/100 ml		5.75×10^5	1.29×10^5
Log Mean - 1 Std. Deviation		6.31×10^4	9.55×10^3
Log Mean + 1 Std. Deviation		5.25×10^6	1.74×10^6
Chlorine Residual, mg/l		Reclaimed Water	House Water
Mean		0.3	4.1
Std. Deviation		0.4	0.4
1976 PROCESSING SEASON			
Peeler & Shaker Belts	n = 20	n = 20	n = 20
Log Mean Plate Count/100 ml	1.72×10^5	1.57×10^5	6.08×10^4
Log Mean - 1 Std. Deviation	2.45×10^4	1.36×10^4	7.63×10^3
Log Mean + 1 Std. Deviation	1.21×10^6	1.82×10^6	4.85×10^5
Waste Slide - Swab Water Count	n = 20	n = 22	n = 22
Log Mean Plate Count/100 ml	1.30×10^5	2.08×10^5	1.45×10^5
Log Mean - 1 Std. Deviation	3.23×10^4	4.05×10^4	5.35×10^4
Log Mean + 1 Std. Deviation	5.20×10^5	1.06×10^6	3.92×10^5
Chlorine Residual, mg/l	Reclaimed Water		House Water
Mean	0.9		0.9
Std. Deviation	0.5		0.6

Reclaimed water quality during the 1975 cooling water trial was; pH = 7.5, suspended solids = 18 mg/l, chlorine residual = 0.6 mg/l, total coliform = 1900/100 ml, total plate count - 5,900/ml. Reclaimed water quality during the 1976 contact container cooling trial was: pH = 7.1, suspended solids = 5 mg/l, chlorine residual = 0.7 mg/l, total coliform = 80/100 ml, total plate count - 140/ml. The chlorine residual was maintained at 1 mg/l in the cooling vessel during the cooling trials by chlorine solution addition.

Since there were no failures of the containers during the contact container cooling trial runs when during each of the two years the bacteriological quality of the reclaimed effluent was not as good as was experienced at other periods during the years it can be concluded that with better bacteriological quality the reclaimed effluent could be used for direct contact container cooling with high confidence in the safety.

Product Cleaning and Conveying

Use of the reclaimed water for initial conveying and cleaning of the raw fruit was conducted during the 1976 processing season. The water was first used during a portion of the peach processing season and compared with house water use during the other portion of peach processing. It was also used during approximately one-half of the apple processing season and compared with the house water used during the other half of the season. During peach processing the dump tank was filled at the start of the trial and chemicals added to increase the specific gravity to float the peaches. Only makeup water was added during the trial. Each of the trials with house and reclaimed water was three days. During apple processing the dump tank was filled each day with new water. Comparison between the use of the two waters was accomplished by sampling the fruit, washing them in a known quantity of sterile water and performing plate count analysis on the sterile water used for washing. Figures 10 and 11 show the results of comparative testing for the two waters used in initial fruit washing and conveying. Figure 10 shows the increase in bacteriological content in the dump tank water and on the peaches following the dump tank and conveying due to the continued use of the same water with minimal makeup addition.

There is no significant difference between the total plate count on the fruit or in the dump tank whether reclaimed or house water was used for the initial fruit dumping and conveying for these two products.

Steam Generation from Reclaimed Water

A portable steam generator was used during the 1976 season to provide steam for trial uses. The reclaimed effluent was used as a water source for the steam generator. The results of equipment cleaning using reclaimed steam and reclaimed water and compared to reclaimed water with house steam and house water with house steam were discussed above. The suitability of the reclaimed water compared to that of the house tap water at Snokist's cannery and to maximum concentrations of constituents recommended for low pressure steam boilers are shown on Table 9. The dissolved oxygen, COD and suspended solids of the reclaimed water exceeded the recommended levels for low pressure steam boiler feed a portion of the time; however, the suspended solids were within the recommended levels of 10 mg/l 70% of the 1976 processing season. The alkalinity of the reclaimed water also exceeded the recommended levels during and for about two weeks following peach processing which used caustic peel. The carryover of volatile organics into the steam generated from reclaimed water was not monitored.

Reclaimed Water Steam for Exhausting

On two different days batches of pears in cans were exhausted prior to placing caps on them using reclaimed water steam. The canned pears were placed in the exhaust box and the exhaust box brought up to temperature using the steam generated from reclaimed water. Then the lids were sealed on them, they were cooked, cooled and retained for comparison with controls exhausted using the normal continuous processing procedures using house steam.

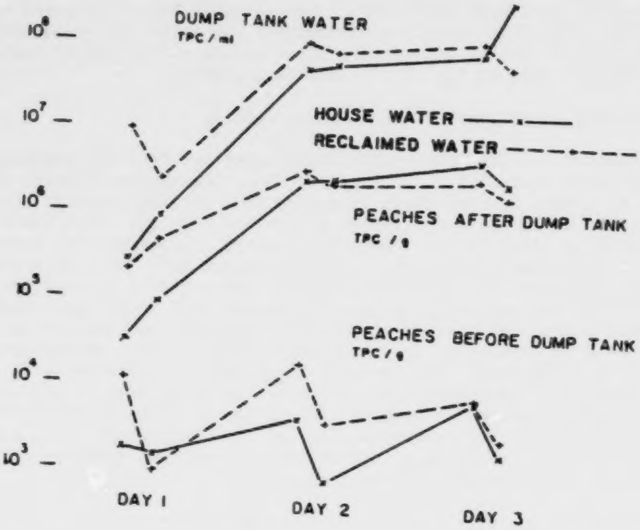

Figure 10. Bacterial count on fruit and in dump tank using reclaimed wastewater and house water for peach dumping and initial conveying.

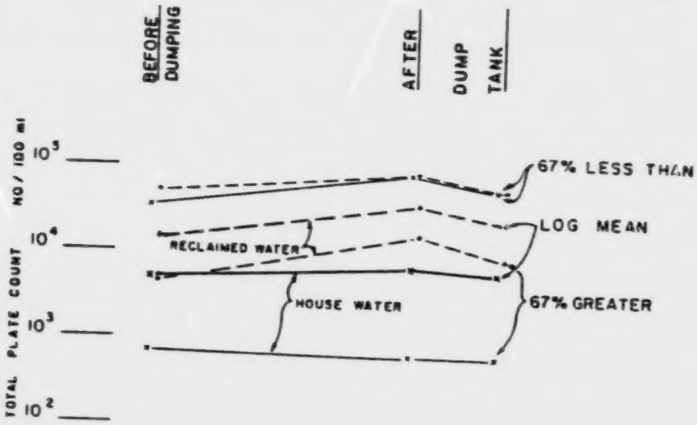

Figure 11. Bacterial count recovered from fruit using reclaimed wastewater and house water for apple dumping and conveying.

There were no significant differences in the fruit quality from grading tests. A triangle organoleptic evaluation of the control and pilot runs were performed by the National Food Processors Association. The NFPA specialist conducting the tests concluded that taking into account all of the results there was no difference in sensory attributes between the control and test samples.

Reclaimed Water Steam for Applesauce Cooking

Applesauce cooking trials with steam generated from the reclaimed water were conducted on two days in 1976. Applesauce cooking is normally done by live steam injection on a continuous basis; however, in order to conserve the amount of product loss the trial run was made on a batch basis in the commercial cooker. For comparison applesauce was also cooked using house steam on a batch basis on each of the two days. Samples from each of the batch runs and from controls processed in the normal continuous processing manner with house steam were graded according to standard scoring procedures and samples were sent to the NFPA Laboratory for organoleptic evaluation. As nearly as could be determined from the test there were no differences in the product which related to the origin of the water used in generating the steam; however, it would be impossible to state that the steam generation from the reclaimed water or the house water is equivalent since the test difference due to handling methods influenced the produce greater than did the steam source.

Reclaimed Water Steam for Sliced Apple Blanching

Sliced apples were blanched on two separate days using reclaimed steam and house steam. In order to conserve product the sliced apples were blanched using reclaimed steam on a batch basis. There also were apples blanched on a batch basis in the commercial blancher using house steam for comparison and control samples were drawn from apples blanched using house steam under continuous processing conditions.

As with the use of the reclaimed steam for applesauce cooking, its use for sliced apple blanching could not be finally judged based on these tests since differences in processing variables unrelated to steam source had greater effect on the product quality than the source of water for steam generation.

DISCUSSION AND SUMMARY

During this two-year study the techno-economic feasibility of reclaiming biological effluent for reuse as a process water supply was evaluated and demonstration of product safety and suitability of the water was attempted. The effluent was reclaimed by filtration through mixed-media pressure filters and subsequently disinfected with chlorine. Reclamation by these processes does not require a high level of technology but relies on unit processes and operations which are used widely in the wastewater and water supply fields and for which equipment is readily available in the commercial market place. Therefore, if feasible, this method of reclamation and processing wastewater for reuse in canneries would be highly desirable and readily implementable throughout the industry. The wastewater treated in the biological system was generated from the processing of high acid foods (apples, peaches, pears and plums) and did not include any sanitary waste. The final processing of the fruit products was by heat treatment in hermetically sealed containers; therefore, transfer of the technology may

TABLE 9. BOILER FEED SUITABILITY

Constituent	Max. Concentration[1]	House Tap Water[2]	Reclaimed Water[2]
Silica (SiO_2),mg/l	30	2.4 ± 0.3	2.5 ± 0.9
Aluminum (Al),mg/l	5	<0.1 - 0.1	<0.1 - 2.2[3]
Iron (Fe),mg/l	1	<0.2	<0.2
Manganese (Mn),mg/l	0.3	<0.01	<0.01
Copper (Cu),mg/l	0.5	<0.02	<0.02
Dissolved Solids, mg/l	700	120 ± 11	290 ± 99
Alkalinity ($CaCO_3$),mg/l	140	61 ± 3	86 ± 62
Hardness ($CaCO_3$),mg/l	20	41 ± 6	30 ± 10
pH, units	8-10	8.1 - 8.3	7.15 ± 0.45
MBAS, mg/l	1	<0.01	<0.1
COD, mg/l	5	5-10	<40,80% of 1976 Pear
Dissolved Oxygen, mg/l	2.5	2.5 - 3.5	7-12
Suspended Solids, mg/l	10	<1	<10,70% of 1976

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[1] Maximum recommended concentration before adding substances used for internal conditioning. From Water Quality Criteria, FWPCA, 1968, Table V-5, for low Pressure Boiler Feed Water (0 to 150 psig).

[2] These columns contain the Mean ± Standard Deviation, or the Range of values observed.

[3] Al in Reclaimed Effluent <0.1 - 0.1 if Alum not used, 1.6 - 2.2 if Alum being used.

have to be limited to processors of high acid commodities using similar processing techniques until demonstration of comparable results in the low-acid and non-thermal processing portions of the industry could be obtained. The reclaimed water was found to be of high quality. In fact, it consistently met the current and proposed U.S. primary drinking water regulations except for turbidity and bacterial counts for all primary parameters which were monitored. Even the bacterial regulation was met during periods of adequate chlorination. However, the turbidity of the reclaimed water was highly variable and dependent on the biological treatment effluent suspended solids level. It appears, based on FDA regulations requiring the use of water which is safe and of adequate sanitary quality that the continuous in-plant reuse of the reclaimed wastewater will require that the water have a consistent and relatively low turbidity level. It was demonstrated during the project that this could be accomplished during extended periods and that the turbidity level in the reclaimed water was highly a function of the biological treatment system. It is felt that at Snokist Growers' cannery stability in the biological treatment system could be maintained by controlling chlorination practices in the cannery and by providing equalization ahead of the biological treatment system to prevent chlorinated discharges from reaching the biological growth and selectively killing organisms which create turbidity problems in the effluent.

When assessing the feasibility of wastewater reclamation/reuse within a food processing establishment it is common to compare the quality of the reclaimed water to the U.S. drinking water regulations; however, in making such comparisons it must be remembered that the drinking water standards were predicted on the potential health effects of full-time, long-term consumption, two liters per day for a lifetime. It is intuitively obvious that the ingestion of any one of these pollutants to this magnitude is highly improbable through the consumption of fruits that have been processed in their own reclaimed processed wastewater.

CONCLUSIONS

This study of cannery processing wastewater treatment, reclamation and reuse has resulted in the conclusions that follow. In considering the widespread application of technology based on these conclusions, it must be remembered that they are applicable to treatment and reclamation of a fruit processing wastewater with no sanitary wastes, and reused in areas of processing high-acid (fruit) products preserved by heat treatment for storage in hermetically sealed containers. Since high-acid products inherently inhibit the growth of many microorganisms, caution should be exercised in application of these conclusions to any other class of food, such as low-acid canned foods and foods not subjected to a terminal thermal process. These conclusions must not be considered applicable to any wastewater containing sanitary wastes.

The project conclusions regarding reuse feasibility have been reviewed and approved by members of the technical advisory committee for the project and their organizations: The EPA Health Effects Research Laboratory; the EPA Industrial Environmental Research Laboratory; the FDA Food Technology Division; the USDA Food Safety and Quality Service; and the National Food Processors Association Western Research Laboratory.

1. Snokist Growers' biologically treated process wastewater can be polished by filtration and disinfected by

chlorination to a quality suitable for reuse within their cannery, except during periods of high suspended solids discharge from biological treatment.

2. The lack of consistency and the potential for equipment malfunctions requires that continuous monitoring of reclaimed water quality be sufficient to provide cannery operating personnel with early warning of deterioration. Residual chlorine monitoring at two points, turbidity monitoring of the reclaimed effluent and low chlorine residual and high turbidity alarms at strategic locations in the cannery are necessary to allow the conversion to alternate water supplies for key cannery processes in the event of effluent quality deterioration.

3. Based on this study, neither the quality nor the safety of the final product is adversely affected by the use of reclaimed processing wastewater. Specific uses evaluated were equipment cleaning in the initial processing area, raw product conveying, container cooling and boiler feed for steam generation. Steam generated from the reclaimed water was used for equipment cleaning in the initial processing area, exhausting, cooking and blanching. Monitoring for volatile organics in the steam and product was not conducted so reclaimed water steam use for exhausting, cooking and blanching cannot be concluded as acceptable.

4. Toxic constituents tested for were not present in the reclaimed effluent in concentrations sufficient to cause public health concern for the final products. Heavy metals were at or below primary drinking water standard maximum permissible concentrations. Pesticides were undetectable or below primary drinking water standard levels. Halogenated organics were below levels found in many drinking water supplies. No buildup of those toxicants in the system with extended reuse was apparent at the testing schedule conducted although added testing would be desirable to confirm these results.

5. The reclaimed wastewater is suitable for full scale continuous use for initial raw product conveying, washdown of equipment in the initial processing area of the cannery (excluding peelers and peeled product conveyors), floor and gutter washdown and direct contact container cooling when the quality is maintained equal to:

   Suspended solids $\leq$ 30 mg/l,
   Turbidity $\leq$ 20 NTU,
   Total coliform $\leq$ 1 organism/100 ml,
   Fecal coliform $\leq$ 1 organism/100 ml,
   Total plate count $\leq$ 500/ml.

6. The reclaimed effluent is suitable for continuous full scale boiler feed except that COD and dissolved oxygen were higher than recommended levels. When the suspended solids are higher in the reclaimed effluent than in the house tap water, it may be less desirable for this use because of potential solids buildup in the ion exchange boiler feed water treatment system. Use of the generated steam

may be restricted to areas where it would not directly contact the product due to the unknown extent of concentration of volatile organics into the steam.

7. Biological effluent quality deteriorated when chlorine was periodically applied in dry form during plant cleanup and flushed to the aeration system at startup, apparently due to selective killing of portions of the activated sludge organisms. The effluent deterioration occurred as high effluent suspended solids.

8. Direct biological effluent multi-media pressure filtration resulted in a normal reduction in suspended solids of 20 to 30 percent. Alum added ahead of direct filtration did not improve the suspended solids removal.

9. Chlorination to 3 mg/l or above with approximately one hour contact, consistently provided bacteriological reduction to: total coliform $\leq$ 1/100 ml; total plate count $\leq$ 500/ml. Organisms reacting to the elevated temperature fecal coliform test were not present in the reclaimed water so long as a positive chlorine residual was present. No salmonella or staphylococcus organisms were isolated from the reclaimed water.

10. The cost of reclaiming wastewater for reuse at Snokist Growers' cannery was about $0.20 per cu. meter, including the cost of capital investment amortization. A new well development would have resulted in a cost of about $0.085 per cu. meter of water including capital investment amortization. The operating cost of the two systems would be similar.

11. Snokist Growers can reduce its effluent emission rate by more than 50% by using its reclaimed wastewater for initial product conveying, container cooling and floor and gutter wash. The BATEA discharge standards can be met during peach and pear processing with this amount of reclamation and reuse.

RECOMMENDATIONS

Recommendations based on the results of this study are divided into categories, those specifically pertaining to Snokist Growers' future operations of the wastewater reclamation system and use of reclaimed water, and those pertaining to the entire food processing industry. These recommendations have been reviewed and approved by the technical advisory committee.

Industrywide Recommendations

1. It is recommended that the food processing industry consider wastewater reclamation and reuse as demonstrated at Snokist Growers' cannery as a viable alternative for reducing pollutant emissions. It should be considered in concert with other pollutant reduction measures such as in-plant controls.

2. It is recommended that industry and regulatory agency

representatives consider means for validating these results to include low-acid and non-thermally processed foods by confirming key results through further studies at appropriate facilities.

Snokist Growers' Cannery Recommendations

1. Further demonstration of consistent performance for reclamation is recommended. Funding of a second phase of the project to demonstrate reclamation and reuse on a full-scale basis for a two-year period should be obtained. Full scale use for can cooling, for initial product conveying and for initial processing area (prior to peeling) washdown would give full use of the reclaimed effluent.

2. Monitoring of the reclaimed effluent during the demonstration seasons should include: coliform, fecal coliform and total plate count analyses to demonstrate sanitary quality; suspended solids and turbidity to demonstrate aesthetic quality; heavy metals, pesticides, polychlorinated biphenyls (PCBs) and halogenated organics to demonstrate whether there is a buildup of toxic or carcinogenic substances during prolonged reuse. The methodology, detection limits, frequency and quality assurance program for all of these tests should be reviewed by concerned regulatory agencies to assure that they will be able to apply the results on an industry-wide basis.

3. Reclaimed water quality criteria for reuse in critical areas such as direct contact container cooling should be set at:

Coliform	Conform to the National Interim Primary Drinking Water Regulations
Fecal Coliform	Conform to the National Interim Primary Drinking Water Regulations for Coliform
Total Plate Count	Equal to or less than 500 ml Average, Equal to or less than $1000/mo tax.
Turbidity	Equal to or less than 20 NTU
Suspended Solids	Equal to or less than 30 mg/l
Chlorine Residual	Measurable residual at the point of use.

ACKNOWLEDGEMENTS

Credits

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Reuse of Municipal Wastewater as Makeup to Circulating Cooling Systems

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ABSTRACT

The reuse of municipal wastewater for industrial cooling is an excellent way of preserving clean waters for other uses. Details have been collected from several countries and there is no doubt that this is a thoroughly practical reuse option.

Makeup waters successfully used fall in the range 10-30 mg/l BOD, 30-50 mg/l o-PO_4, 1000-1500 mg/l TDS and 30-70 mg/l NH_3. The major problems are phosphate scale and biological fouling. Usual treatments are lime clarification and chlorination.

Most of the industrial users are power plants, which use high alloy metals to avoid corrosion, but industries using carbon-steel heat exchangers have not found much corrosion.

An average municipal wastewater composition in the western United States has been chosen for study. With reasonable biological control the water can be concentrated 3 to 5 fold before scaling occurs. A two stage lime-soda treatment will yield a water fit for a 15 fold concentration. An unconventional biological treatment, which is expected to give a particularly good removal of phosphate, is preferred if high concentrations are wanted. Lime treatment is needed even after the unconventional biological treatment because of the high silica content of the exemplary water, but lower phosphate concentration makes the lime treatment smaller and simpler.

INTRODUCTION

The reuse of municipal sewage as makeup to cooling towers is a potentially excellent method of preserving large quantities of pristine waters for domestic and recreational use. Reuse of municipal wastewater for industrial cooling in the United States amounted to about 154 million gallons/day in 1971.[1] Although 80 percent of this volume was used for once-through cooling, there are currently many examples of recirculation-type cooling systems operating satisfactorily on sewage plant effluents.[2,3]

On Tables 1 and 2 are given a summary of some reported current practice. The published statements are not always clear on what treatment is used or why.

Sewage differs from carriage water in having a high organic content, an increased inorganic content and a specific addition of ammonia and phosphate.

In the following we will outline the problems to be expected when using wastewater, estimate the probable concentrations achievable with minimum treatment and show what is known about more thorough treatment for higher concentrations. We have not addressed the possible distribution

TABLE 1. SELECTED ESTABLISHED USERS OF TREATED SEWAGE FOR COOLING

(a) United States

Company	Plant	Location	Generating Capacity MW	Treated Sewage Consumed* mgd	Treated Sewage Consumed* l/s	Date Started	Reference
Southwestern Public Service	Nichols PS**	Amarillo, Texas	470	13.7	600	1961	16, 21
Southwestern Public Service	Jones PS	Lubbock, Texas	500	3.5	153	1970	19, 21
Nevada Power Co.	Clark PS	Las Vegas, Nevada	86	1	44	1964	21
Nevada Power Co.	Sunrise PS	"					
Public Works Dept.	Magnolia PS	Burbank, CA	70	2	88	1968	11, 21
Public Works Dept.	Olive PS	Burbank, CA	99				
Zia Corporation		Los Alamos, Texas		0.3	13	1951	21
El Paso Products Co.	Petro-chemical	Odessa, Texas		6	264		15,20
City of Denton	Power Station	Denton, Texas	188				1
Bethlehem Steel Company	Steel Works	Baltimore, MD		120	5,280		1

(continued)

*Mainly for cooling, but in some cases also for boiler feed and dilution of blowdown.

**Power Station.

TABLE 1 (continued)

(b) Other

Company	Plant	Location	Generating Capacity MW	Effluent water Consumed*		Date Started	Reference
				mgd	l/s		
Central Electricity Generating Board	Croyden PS	S.E. region U.K.*	210	∿2	∿79	1950	12
Electricity supply Commission	Kelvin A&B PS	Johannesburg, RSA**	600	8.4	368	1957 & 1963	10
	Orlando P.S.		300	6.0	262	1942	10

*Total consumption of sewage effluent for cooling in U.K. is 13.2 mgd (Ref. 17).

**Total consumption of sewage for power station cooling in South Africa is 28.5 mgd (Ref. 18).

TABLE 2. SEWAGE EFFLUENT QUALITY AND TREATMENT

(a) United States

Company/plant	Effluent sewage water quality BOD mg/1	O-PO$_4$ mg/1	TDS mg/1	NH$_3$ as N mg/1	Treatment	No. of cycles of concentration
Nichols P.S.	10	50	1400	73	Lime clarification, pH adjustment shock chlorination, corrosion inhibitor	3-5
Jones P.S.	25	29				
Clark P.S. and Sunrise P.S.	20	35	1000-1500		Shock chlorination lime clarification, pH adjustment, corrosion inhibitor	
Magnolia P.S. and Olive P.S.	2	30	750		Shock chlorination, pH adjustment, corrosion inhibitor, antifoam agent. Biological fouling sometimes troublesome.	2-4
Zia Corporation		35			Shock chlorination, pH adjustment corrosion inhibitors. Algal growth controlled by intermittent drying of towers.	4-5
El Paso	10	40	1300	28	Lime clarification, recarbonation, pH adjustment, filtration, ion exchange softening, antifoam agent	7-7.4

(continued)

TABLE 2. (continued)

Company/plant	Effluent sewage water quality				Treatment	No. of cycles of concentration
	BOD mg/l	O-PO$_4$ mg/l	TDS mg/l	NH$_3$ as N mg/l		
(a) United States continued						
Denton P.S.	30		130		Shock chlorination, pH adjustment, corrosion inhibitor (treatment inadequate).	
Bethlehem Steel						once through
(b) Other						
Croyden P.S.	21	15	--	29	Filtration, biological oxidation of NH$_3$ in tower for pH control (NH$_4$-salt sometimes added),	
Kelvin P.S.	--	~25	--	5.5	Shock chlorination, pH adjustment, Phosphate scaling a problem when pH not adequately controlled,	2 - 4
Orlando P.S.	--	--	--	--	Shock chlorination; (phosphate precipitation occurs in equalisation dam)	2-4

of pathogens from the sewage by drift from the cooling tower. A preliminary study was made by Lewis in 1974.[4]

CONTAMINANTS IN SEWAGE AND THE PROBLEMS

Foaming Serious foaming can cause loss of control of the cooling tower[20] and can not be allowed. Antifoaming agents can be used to control periodic foam build-up.[2,11,20] Continuous high concentrations of detergents may be controlled more economically by removal with activated carbon adsorption or by foam stripping. Foaming agents in sewage are derived mostly from domestic detergents and now that the active ingredients are being made biodegradable foaming is becoming less of a problem. Biological oxidation can usually reduce the concentration of foaming agent (linear alkyl sulfonates, LAS) to below the required 0.5 mg/l.

Ammonia We are not certain of the gravity of the problems caused by ammonia. Ammonia will be stripped in a cooling tower[9] and will not concentrate in the circulating water. The threshold odor limit for ammonia has been given as 21.4 ppm.[14] If all the ammonia entering a cooling tower is stripped, the ammonia concentration in the plume will be about one twenty-fifth that of the ammonia concentration in the makeup water. This is for a cooling tower operating with a liquid to gas flow ratio of two to one, 2% of the circulating water evaporated per cycle and ten cycles of concentration. Ammonia in sewage will not give odor problems. Ammonia is corrosive to copper and copper bearing alloys which should not be used for heat exchangers in plants using sewage. Ammonia reacts with chlorine forming chloramines which are less effective as biocides and are longer lived in blowdown. Chlorination is successfully used today and non-chlorine biocides are available. Ammonia can interfere with lime softening as is discussed later.

Bacterial Slime Even after receiving a secondary treatment of biological oxidation sewage is highly nutrient. Slime and algae growths are often reported as being the most serious problems when using municipal waste water in a cooling tower.[3] Nevertheless disinfection by chlorination, frequent shock treatment, is normally adequate. Biocide requirements are from 1.5 to 10 times the level required for fresh water makeup.[2] Biological activity in a cooling tower is not necessarily bad. It has been found, for example, that phenol is much reduced in a cooling tower,[6,8,9] at the same time that chlorination is used for slime control.

Calcium Phosphate Deposits Calcium phosphates can deposit and form scale. However, deposition is far less troublesome in treated sewage than in water without the organic content of sewage. In fresh waters a limit of 12 mg/l orthophosphate has been recommended.[5] This is much less than a limit of 140 mg/l suggested for clarified sewage effluent.[21] The solubility of calcium phosphate decreases as the pH increases. Calcium phosphate can be deliberately precipitated by adding lime. Alternatively, precipitation can be prevented in circulating cooling water by lowering the pH. We feel that a relationship between the concentrations of calcium and orthophosphate, and the pH would be more useful to operators than a simply stated limit of concentration. The following relationship is suggested for trial and we would be grateful to anyone who can tell us how useful it is.

Following McCoy[22] we write

$$K_1 = 7.5 \times 10^{-3} = [H^+] \times [H_2PO_4^-]/[H_3PO_4] \qquad (1)$$

$$K_2 = 6.2 \times 10^{-8} = [H^+] \times [HPO_4^{=}] / [H_2PO_4^{-}] \qquad (2)$$

$$K_3 = 4.8 \times 10^{-13} = [H^+] \times [PO_4^{\equiv}]/[HPO_4^{=}] \qquad (3)$$

and total orthophosphate

$$[o\text{-}PO_4] = [H_3PO_4] + [H_2PO_4^{-}] + [HPO_4^{=}] + [PO_4^{\equiv}] \qquad (4)$$

we assume that concentrations equal activities and that no other species are important. De Boice and Thomas[25] used a much more complex procedure for their work, accounting for the presence of carbonate species plus twelve complexes. Reference 25 can be referred to if more detail is wanted. Equations (1) through (4) give

$$PO_4^{\equiv} = \left[o\text{-}PO_4\right] \times K_1K_2K_3/F = \left[o\text{-}PO_4\right] \times 2.23 \times 10^{-22}/F \qquad (5)$$

where

$$F = [H^+]^3 + K_1[H^+]^2 + K_1K_2[H^+] + K_1K_2K_3 \qquad (6)$$

$$= 10^{-3pH} + K_1 \times 10^{-2pH} + K_1K_2 \times 10^{-pH} + K_1K_2K_3 \qquad (7)$$

$$= 10^{-3pH} + 7.5 \times 10^{-3-2pH} + 4.65 \times 10^{-10-pH} + 2.23 \times 10^{-22} \qquad (8)$$

We considered the solubility of tricalcium phosphate given by McCoy,[22]

$$[Ca^{++}]^3 \times [PO_4^{\equiv}]^2 = 5 \times 10^{-30} \qquad (9)$$

and changed the units to concentration of calcium in mg/l as $CaCO_3$ (written CaH) and total orthophosphate in mg/l (written $o\text{-}PO_4$) to obtain

$$1.5 \text{ Log CaH} + \text{Log } o\text{-}PO_4 - \text{Log F} = 19.478 \qquad (10)$$

We also considered the solubility of hydroxyapatite given by Truesdall and Jones[23] at 30°C to obtain

$$1.667 \text{ Log CaH} + \text{Log } o\text{-}PO_4 - \text{Log F} + pH/3 = 21.670 \qquad (11)$$

Some calculations from Equations (1) and (11) are presented in Table 3A. Clearly Equations (10) and (11) suggest much lower concentrations than have been successfully used in practice.[2,21] In their work DeBoice and Thomas[25] have successfully used a pseudo-solubility product

$$[Ca^{++}]^3 \times [PO_4^{\equiv}]^2 = 10^{-25.46} = 3.467 \times 10^{-26} \qquad (12)$$

which results in Equation (13)

$$1.5 \text{ Log CaH} + \text{Log } o\text{-}PO_4 - \text{Log F} = 21.399 \qquad (13)$$

Calculations from Equation (13) are given on Table 3B. Experience is lacking, but Equation (13) seems to give answers that are safe to use. Equation (13) is suggested for a control equation.

Other Scale Formation Because wastewater is always more concentrated than carriage water, scale formation will always be more probable.

TABLE 3A. EQUILIBRIUM CONCENTRATIONS OF CALCIUM
(in mg $CaCO_3$/l) FOR VARIOUS TOTAL ORTHOPHOSPHATE
CALCULATED FROM EQUATIONS (10) AND (11)

		Equilibrium Calcium Concentration					
		for tricalcium phosphate			for hydroxapatite		
orthophosphate (mg/l)		10	3	1	10	3	1
pH	Log F						
5.0	-12.122	1.73×10^4	3.85×10^4	8.02×10^4	1.34×10^4	2.76×10^4	5.34×10^4
6.0	-14.099	830	1850	3850	552	1140	2200
6.5	-15.045	194	434	902	119	244	472
7.0	-15.915	51	114	237	28	58	113
7.5	-16.653	16	37	76	8	17	32
8.0	-17.268	6	14	30	3	6	11
9.0	-18.325	1	3	6	0.4	0.8	1.6

TABLE 3B. EQUILIBRIUM CONCENTRATIONS OF CALCIUM CALCULATED FROM EQUATION (13)

10 mg/l Orthophosphate

pH	Calcium as mg/l $CaCO_3$
5.0	330,000
6.0	16,000
6.5	3,700
7.0	980
7.5	310
8.0	120
9.0	24

During municipal use calcium and magnesium usually increase and silica may increase. Carbonate is added by biological treatment.

INVESTIGATION OF A TYPICAL WASTEWATER

On Table 4 are shown typical compositions of sewage, effluent from secondary treatment and expected effluent from the Bardenpho process (which is described later). They are taken from analyses of wastewaters in the western United States. The theoretical permissible concentration of the effluent from secondary treatment which will not cause precipitation has been estimated. The alkalinity is very high, as is shown on Figure 1 which is a graph of alkalinity against pH. The alkalinity is one hundred times the alkalinity in equilibrium with the atmosphere. Also shown on Figure 1 are some other waters for comparison. The Alabama River is an excellent make-up water. The Illinois River is a poor make-up water. The treated sewage is worse still.

The water is theoretically saturated in $CaCO_3$ as received. If various fractions of the alkalinity are neutralized with sulfuric acid, the following results are obtained:

% Alkalinity Neutralized	pH of Acidified Make-up	Cycles at Saturation	pH at Saturation
25	6.6	1.2	7.0
50	6.2	1.6	7.0
75	5.7	2.4	7.0

These estimates were made by the procedure shown, for 75 percent of the alkalinity neutralized with acid, on Figure 2. Acidification changes the alkalinity from 5 meq/l to 1.25 meq/l, and the pH from 7.3 to 5.7. As the water is circulated, water and carbon dioxide are assumed to volatalize in such a ratio that the composition moves along the line from $A = 1.25 \times 10^{-3}$, pH = 5.7 to the arbitrary point $A = 1.1 \times 10^{-2}$, pH = 8.8. Any other arbitrary point can be used. At 2.4 cycles the alkalinity reaches 3.0×10^{-3}, the pH reaches 7.0 and the water is theoretically saturated in $CaCO_3$.

Using the procedure of Marshall and Slusher[27] at 38°C for gypsum precipitation, the water is saturated at 6 cycles if 100 percent of the alkalinity is replaced by equivalent sulphate.

TABLE 4.

Typical Compositions of Sewage and Treated Sewage

	Primary Effluent	Effluent from 2^{dary} Treatment	Effluent from Bardenpho process
Total dissolved solids		550	
Specific conductance, (micromhos at 18°C)		800	
Total hardness (as $CaCO_3$)		200	
Silica (as SiO_2)		30	30
Calcium (as $CaCO_3$)		130	130
Magnesium (as $CaCO_3$)		70	70
Iron (as Fe)		0.5	
Zinc (as Zn)		0.2	
Copper (as Cu)		0.04	
Nickel (as Ni)		0.18	
Chloride (as Cl)		100	100
Sulfate (as SO_4)		180	180
Orthophosphate (as PO_4)		20	8
Total phosphate (as PO_4)	38	20	8
Ammonia (as N)		15	
Total nitrogen (as N)	50	20	7
Suspended solids	135	20	20
Turbidity units		14	
pH		7.3	
M alkalinity (as $CaCO_3$)		250	
BOD_5	175	20	20
COD	270	50	50
ABS		3	
Chlorine demand		20	

mg/l unless otherwise specified.
Based on data from references 2, 11, 24 and 26.

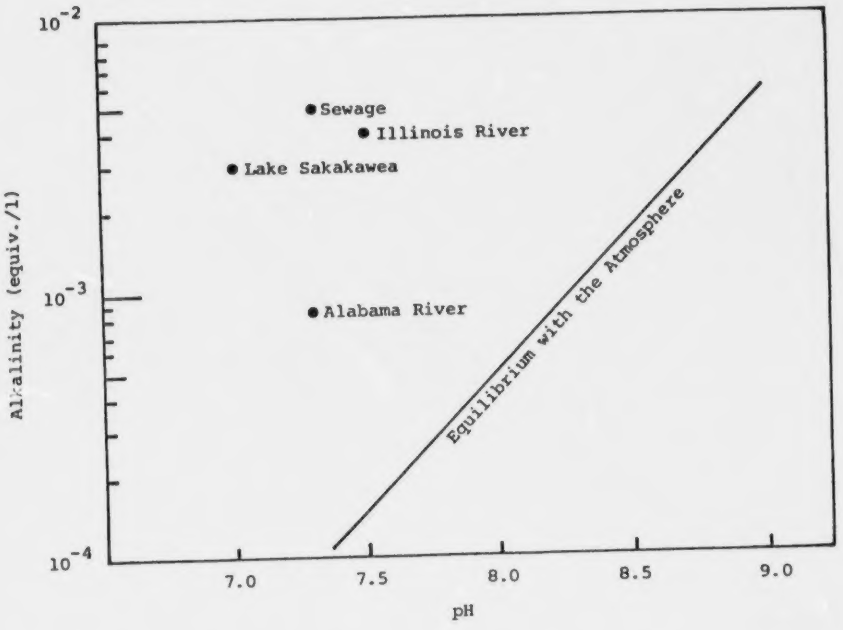

Figure 1. Alkalinity and pH of some waters.

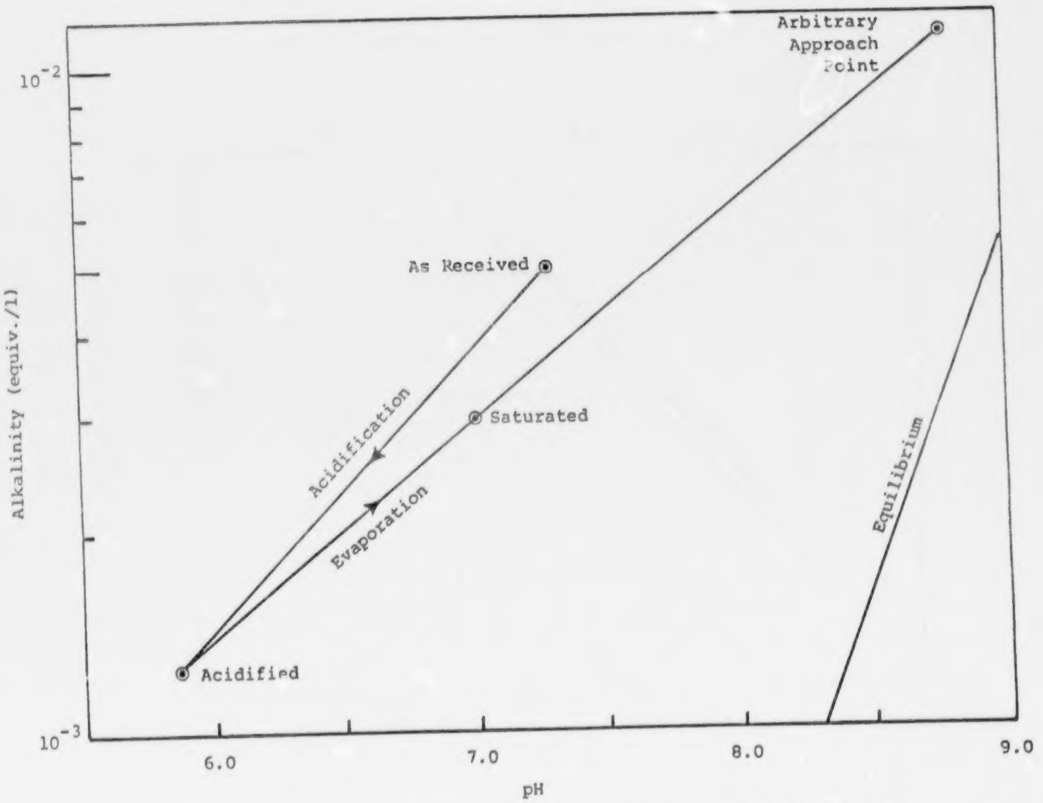

Figure 2. Calculation of permissible concentration with acidified feed.

Permissible concentrations before calcium orthophosphate precipitates have been calculated using Equation (13)

pH	Cycles at Saturation
6	13.5
6.5	5.7
7	2.5
7.5	1.3

The possible precipitation of magnesium silicate in the form of sepiolite has been estimated using data from dissolution given by Christ and others[28] (and by Truesdall and Jones[23]), and data from precipitation in sea water given by Wollast and others[29]:

	Cycles at Saturation	
pH	Data from Christ	Data from Wollast
6	104	271
7	16	43
7.5	6.5	17
8.0	2.6	7

Magnesium silicate precipitation does not seem to be a problem.

Other estimates are shown on Table 5. The most likely limits, if acidified, are firstly calcium phosphate and secondly calcium sulfate and silica. The upper limit of current practice shown on Table 3, 4 to 5 cycles, is reasonable.

OBTAINING HIGHER CYCLES

If four to six cycles of concentration are obtained the blowdown is 25 percent to 19 percent of the makeup. Quite a lot of acid is needed costing about 1.8¢/m^3 makeup (6.8¢/1000 gals makeup). The total dissolved solids in the blowdown after acidification and concentration will be in the range 2,400 - 3,200 mg/l and there will be organic contamination as well. If disposal of blowdown is difficult it may pay to reduce the quantity. We have looked at ways of reaching 12 to 16 cycles of concentration thus cutting the blowdown rate to one half or one third.

TABLE 5. MAXIMUM CYCLES OF CONCENTRATION AS LIMITED BY COMPONENTS IN THE UNTREATED EFFLUENT WATER SPECIFIED IN TABLE 2-11

Component	Makeup Concentration	Limit in Cooling Water	Max. No. of Cycles
SiO_2	30 mg/l	150 mg/l (Ref. 22)	5
o-PO_4	20 mg/l (as PO_4)	120-140 mg/l (Ref. 21)	6-7
[Ca][Alk]	32,500 (mg/l $CaCO_3$)^2	41,600 (mg/l $CaCO_3$)^2 at pH 7.3 (Ref. 30)	*
[Mg][SiO_2]	510 (mg/l ions)^2	35,000 (mg/l ions)^2 (Ref. 31)	8
[Ca][SO_4]	9,360 (mg/l ions)^2	(580,000)(mg/l ions)^2 (Ref. 31)	8
[Ca][SO_4]	**21,840 (mg/l ions)^2	(580,000)(mg/l ions)^2(Ref. 31)	5
NH_3	15 mg/l N	75 mg/l N (Ref. 33)	5
Suspended Solids	20 mg/l	200-400 mg/l (Ref. 31)	***10-20

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*$CaCO_3$ will probably not form scale even when present at concentrations many times its equilibrium solubility[32]

**Following neutralization of 250 ppm M-alkalinity with sulfuric acid.

***Assuming negligible pickup of dust from the atmosphere.

LIME TREATMENT

Cummings,[35] and Kluesner et al,[33] and O'Farrell and Menke[34] have studied the addition of lime to secondary treated sewage. Merrill and Jordan[36] have studied the addition of lime to degritted raw sewage. Some of these results have been replotted in matching units on Figures 3 and 4. The authors all found, and the figures show, that:

a) Adequate phosphorus removal occurs at a pH greater than 10 to 10.5. Kluesner found that treated water was low in eutrofication and gave low algae growth in storage or in the tower.

b) A pH of 10.5 to 11 was needed for adequate removal of magnesium.

c) At a pH high enough to remove magnesium, calcium was added to the system. All authors studying secondary treated sewage obtained adequate control of calcium by recarbonation to pH 10 and addition of soda ash.

d) Merrill and Jordan reported dissolved carbonate in the effluent as:

pH	Carbonate (mg/l as $CaCO_3$)
11	140
10.5	200

Cummings reported, at pH 10:

carbonate	110 (mg/l as $CaCO_3$)
Alkalinity, total	216 (mg/l as $CaCO_3$)

e) Kluesner reported unexpectedly unsatisfactory silica removal. For best removal the reaction zone residence time should be at least 20 minutes and the reaction zone suspended solids at least 10,000 mg/l. Then silica was removed at the rate of 1 mg SiO_2/7 mg Mg hardness.

f) Kluesner recommends removal of ammonia by nitrification ahead of the cold lime treatment. Nitrification is the reaction

$$NH_4HCO_3 + O_2 \rightarrow HNO_3 + CO_2 + 2H_2O$$

and causes the removal of bicarbonate and ammonia. Both of these species are buffers and consume lime when it is added to raise the pH towards 11. Thus nitrification reduces the consumption of lime. Prior removal of ammonia was also found to improve removal of magnesium (for reasons unknown) and to improve and make reproducible calcium removal in the second stage. Phosphorus and silica removal were little influenced by the ammonia concentration.

g) O'Farrell and Menke used ferric chloride as a coagulant in the second stage reactor-clarifier.

To further investigate lime treatment a flow rate of 38 m^3/min (10,000 gpm, 14.4 x 10^6 gal/day) was assumed. This is approximately the makeup

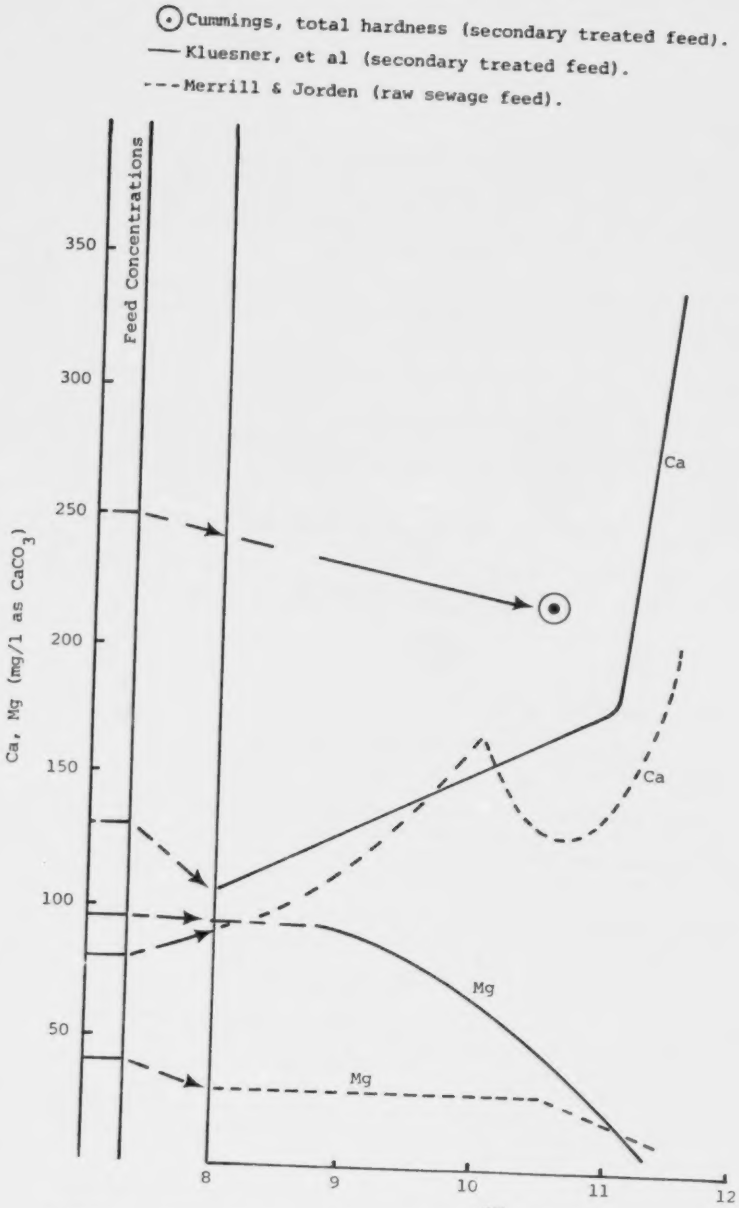

Figure 3. Concentrations in effluent from cold lime treatment of sewage.

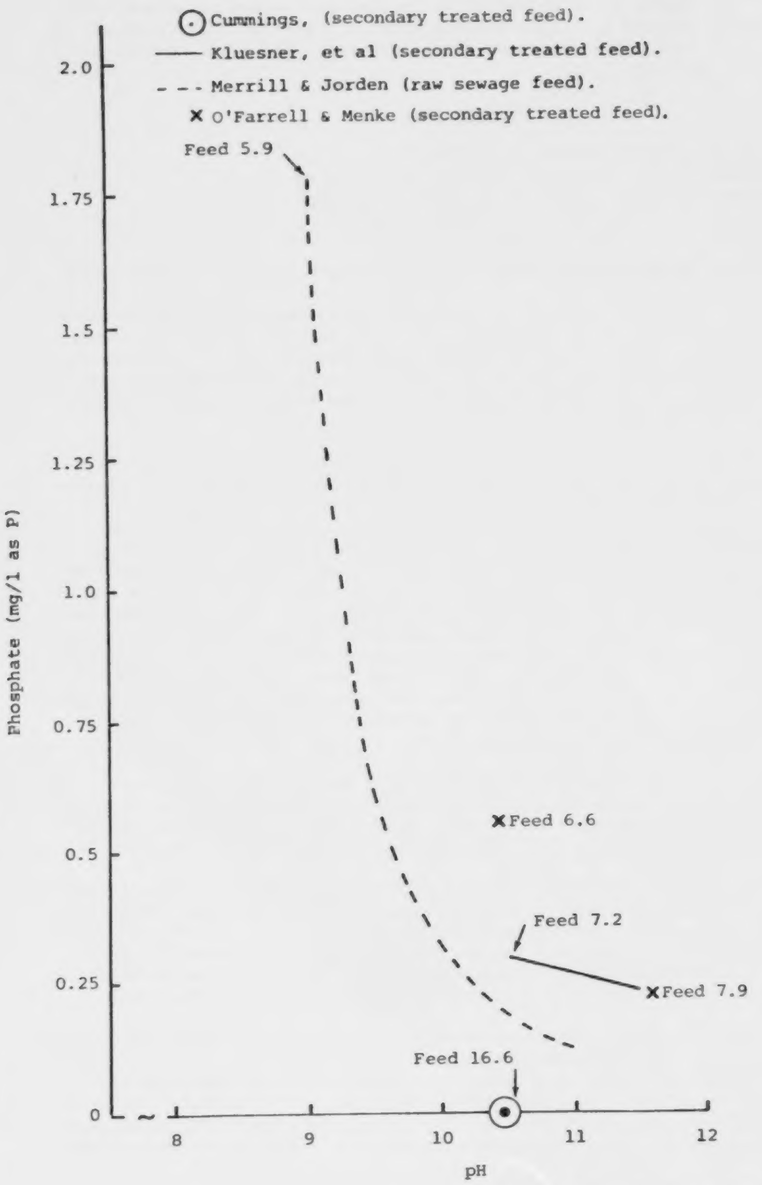

Figure 4. Concentrations in effluent from cold lime treatment of sewage.

to the cooling tower of a 1,000 MWe generating plant when high cycles of concentration are used. The treatment is pictured in Figure 5. A two stage lime treatment is necessary to control silica and magnesium. The equipment pictured in Figure 5 costs about 3.7 million dollars installed This is without lime slakers or sludge burners. The major operating costs are at least

	¢/1000 gals	¢/m^3
Capital related costs	13.3	3.5
Chemicals	6.7	1.6
Labor	3.0	0.8
	23.0	5.9

This is an incomplete and rough estimate but the costs are not excessive.

Since one problem is control of silica it might be advantageous to place the lime treatment in a sidestream taken off the hot side of the circulating water. Silica should be kept to 150 mg/l in the circulating water and magnesium may have to be added to the precipitator to bring down enough silica. The hot water temperature may be of considerable help.

The throughput of a sidestream lime treatment depends on the concentration permissible in the circulating water and the concentration obtainable in the effluent from treatment. Each precipitating species must be estimated in turn to find out which species limits the flow. For this water the limiting species is calcium phosphate. If we consider a lime treatment handling a flow rate equal to the makeup rate, and if PO_4 is reduced to 0.5 mg/l (0.16 mg/lP), then the material balance on PO_4 gives the circulating concentration as 19 mg PO_4/l. From Equation (13) at pH = 7.5, the circulating concentration of calcium should be held to 205 mg/l as $CaCO_3$. The side stream treatment must reduce the calcium to 89 mg/l as $CaCO_3$ (36 mg Ca/l). An effluent from lime treatment of 0.5 mg PO_4/l and 36 mg Ca/l is attainable but much lower concentrations are not attainable. A side stream lime treatment can not handle a lower flow rate than a makeup lime treatment.

If acidification is used to hold alkalinity in the circulating water equivalent with the calcium (205 mg/l as $CaCO_3$) we would expect no scale from calcium carbonate. Furthermore, much of the precipitation on the side stream can be made with lime, minimizing the cost of soda ash.

Calcium sulfate is not a problem at all. Calcium sulfate is poorly ionized and so long as calcium is kept below about 200 mg Ca/l (500 mg/l as $CaCO_3$) the sulfate concentration can be very high indeed. This is readily calculable and has been demonstrated by Klen and Johnson.[13] In fact, a high sulfate concentration removes calcium ions from solution and is helpful in preventing the precipitation of calcium phosphate.

A possible advantage of a side stream treatment over a makeup treatment is that upsets can be cured by passing an increased flow through treatment rather than by blowing down. The extent to which concentrated organics interfere with side stream precipitation is not known. Ammonia will not concentrate and will not interfere. We suggest piping so that the treatment can be placed either in the side stream or in the makeup.

BIOLOGICAL OXIDATION OF SEWAGE

If sewage is intended for use in a cooling tower, it is quite important

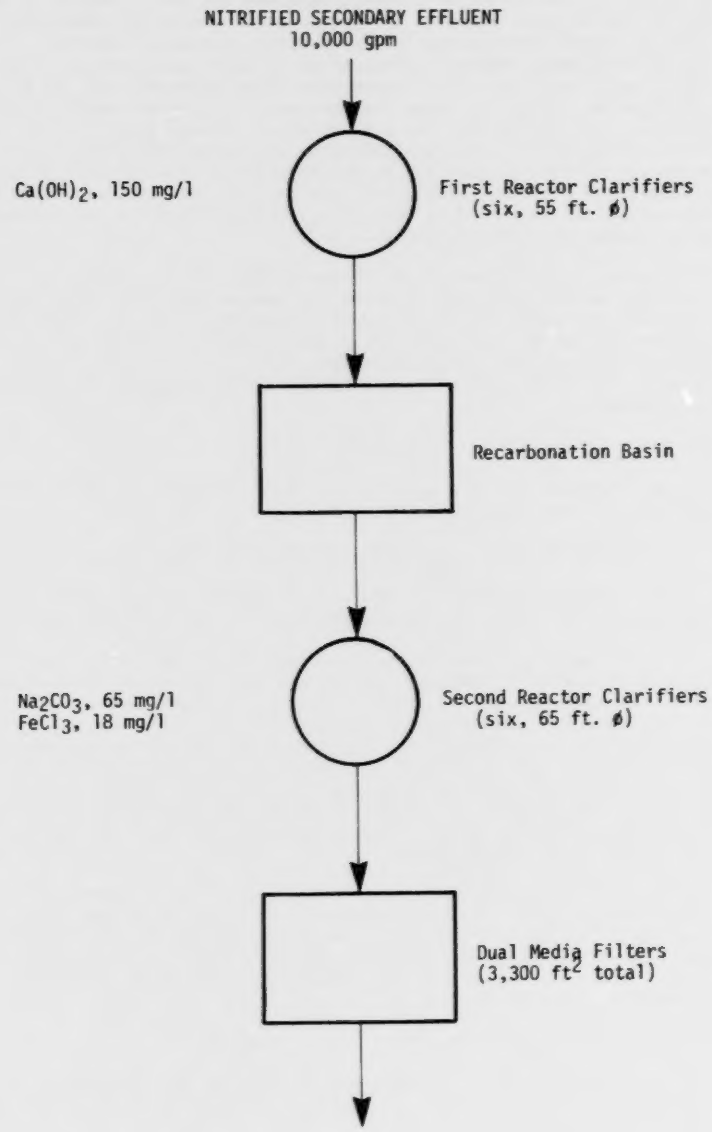

Figure 5. Lime treatment of secondary treated sewage.

to remove phosphate. Recent research[37-42] has indicated that special arrangements of bio-reactors may be devised to achieve high removal of N and P as well as BOD by a single sludge activated sludge system. One such system, the Bardenpho process, involves the use of anoxic, anaerobic and aerobic bio-reactors in appropriate sequence to achieve BOD removal, nitrification, denitrification and phosphorus removal. An anoxic environment means an environment in which dissolved molecular oxygen is absent, but other oxygen-containing oxidants, such as nitrate, are present. Anaerobic means the absence of molecular oxygen and nitrate. Most experience has been obtained abroad, especially in South Africa. Available literature indicates that pilot tests appear to be successful[40-44]; at least two municipal plants, 45 x 10^3 and 150 x 10^3 m^3/day (11.9 x 10^6 and 39.6 x 10^6 gals/day) in capacity, have been in operation, and four or five additional full-scale plants will probably be in operation in South Africa in 1979.

A schematic flow diagram of the system is shown in Figure 6. As in conventional activated sludge systems, the sewage will first flow through a primary clarifier to remove suspended solids. Then the sewage flows through four biological reactors, designated as primary anoxic (PAn), primary aerated (PA), secondary anoxic (SAn), and secondary aerated (SA) basins. The functions of these reactors are described in the following paragraphs.

The PAn basin receives the following streams:

1. Effluent from the primary clarifier containing organic carbon, ammonia nitrogen and phosphate;

2. Recycled sludge from the secondary clarifier;

3. Recycled mixed liquor from the PA basin containing less organic carbon, mostly nitrate rather than ammonia nitrogen, and phosphate.

In the PAn basin no oxygenation is allowed so the dissolved oxygen (DO) is essentially zero. However, proper mixing is provided so that the biological sludge will remain suspended. Under such anoxic conditions, biosynthesis and substrate nitrate respiration will take place. In the substrate nitrate respiration nitrate will be reduced to nitrogen gas, the substrate (organic carbon) will be oxidized to carbon dioxide, and energy will be released and utilized for biological needs. The PAn basin achieves BOD removal, denitrification and conversion of some substrate to biological sludge. Any incoming ammonia will be passed on to the PA basin for nitrification.

The PA basin is essentially the aeration basin of a conventional activated sludge plant. It is oxygenated to maintain DO in the range of 1 to 2 mg/l. It is designed to achieve nitrification and this is done by maintaining the mean cell residence time, Θ_c, above a certain critical limit, (Θ_c) lim., which has been related[43] to the water temperature, T (^oC), by the equation

$$(\Theta_c) \text{ lim.} = 3.05\ (1.127)^{20-T}$$

Although the nitrifying bacteria in the PA basin will be subject to anoxic condition in the PAn and SAn basins, no adverse effect has been observed.

The physical conditions in SAn are similar to those in the PAn basin; no oxygenation, but proper mixing provided. However, the reaction

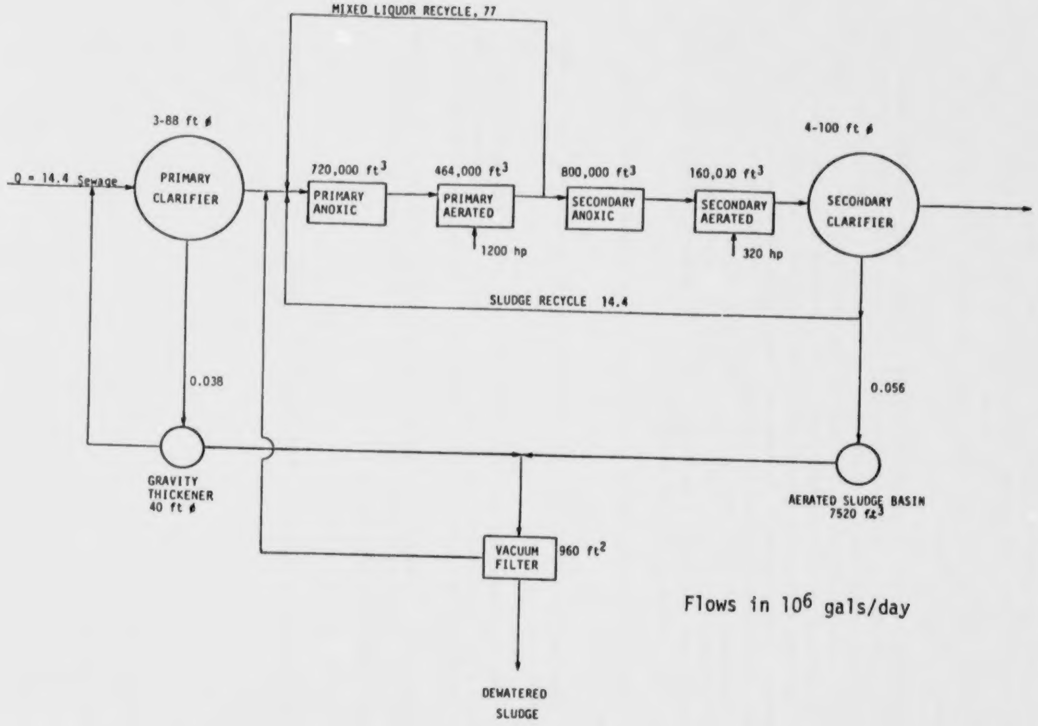

Figure 6. Schematic flow diagram of sewage treatment system for nitrogen and phosphorus removal.

taking place is different. Here endogenous nitrate respiration rather than substrate respiration will occur. In the absence of high substrate concentration, the biomasss rather than substrate will be oxidized while nitrate is reduced to nitrogen gas. The rate of endogenous nitrate respiration has been found to be much lower than that of substrate nitrate respiration.[43] At 20°C the ratio of the reaction rates (substrate nitrate respiration: endogenous nitrate respiration) is about 3.6/1.3 = 2.77 when the rates are measured in mg NO_3^- - N/(gm MLSS) (hr). Endogenous nitrate respiration also shows more temperature dependence than substrate nitrate respiration.

It is preferable that, as a result of denitrification, the SAn basin approach an anaerobic stage as distinct from an anoxic stage. The presence of an anaerobic stage before the final aeration in the SA basin has been found to be critical to the phosphorus removal.[40-43] Close monitoring of DO and nitrate is necessary. The mechanism of phosphorus removal has not been well established. The general consensus is that the removal is biological in nature although pure chemical precipitation has been proposed as a possible mechanism.[38-40] Following the SAn basin is the secondary aerated (SA) basin, where the mixed liquor will be well aerated and phosphorus will be incorporated into the sludge. The DO in the mixed liquor is usually maintained at 3 to 4 mg/l. Under such condition, the following will be achieved:

1. Denitrification, which would impair subsequent clarification, will be stopped;

2. Release of phosphorus, which might occur in the SAn basin, will be stopped;

3. The CO_2 generated will be stripped from the mixed liquor and this will lead to a higher pH. Also, the reduced CO_2 concentration can result in reduced acid or lime requirements in subsequent treatment.

The sizing shown in Figure 6 was derived using the methods given by Barnard.[43] This plant will cost about 21.1 million dollars to install. The operating costs are about:

	10^6 \$/yr
Capital amortization and maintenance	4.01
Labor	0.16
Power	0.47
Total, \$/yr	\$ 4.6
¢/1000 gal	97
¢/m^3	26

These costs can be compared with the costs of the conventional plant to accomplish the same objective shown in Figure 7. A single sludge plant is shown because it is cheaper than a two sludge plant; that is, oxidation and nitrification are achieved in the same basin. This plant costs about 28.9 million dollars to install, of which 12.9 million dollars is for the denitrification. The operating costs are about:

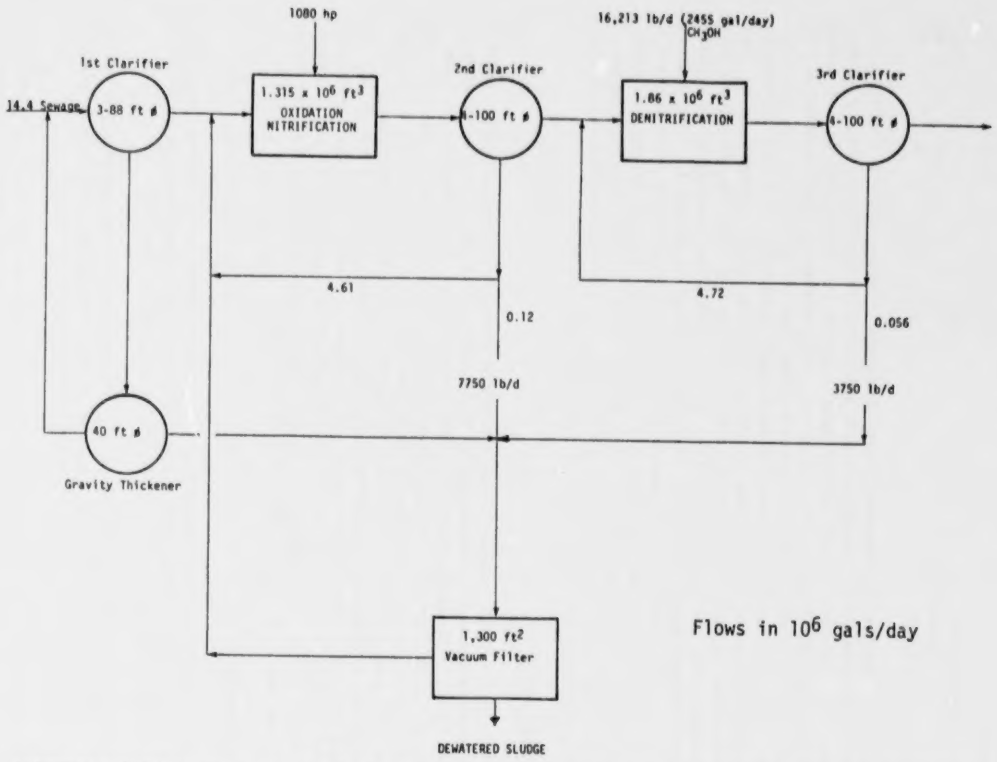

Figure 7. Schematic flow diagram of standard one-sludge sewage plant for nitrification and denitrification.

	10^6 ¢/yr		
	oxidation nitrification	denitrification	Total
Capital amortization and maintenance	3.04	2.45	5.49
Labor	0.1	0.06	0.16
Power	0.29	--	0.29
Methanol	--	0.33	0.33
Total $/7r	3.43	2.84	6.27
¢/1000 gal	71	59	1.30
¢/m^3	19	16	35

It should be noted, however, that the above costing does not include the cost for phosphorus removal, which was included in the Bordenpho process. Our costs do not include site preparation or buildings but do use industrial, not municipal costs for money. The costs are for industrial, not municipal practice, and are intended for comparison of the two plants. Of course an industrial user of municipal wastewater may not control the treatment but if he does, the Bardenpho process seems certain to be less expensive for nitrification plus denitrification than the conventional design, with the high probability of a much better removal of phosphate. An estimated analysis of the effluent is given in Table 4. Denitrification is not essential. Kleusner and others[33] considered only partial nitrification using a trickling filter which is certainly cheaper than anything we have considered. The advantage of a more thorough sewage treatment will lie in removal of phosphate which, as we have seen, is what controls the size of a side stream lime treatment.

CONCLUSIONS

There are enough successfully operating cooling systems using treated sewage as makeup to establish that control of biofouling and foaming is practical. Because sewage is more concentrated than the water from which it is derived, and particularly because phosphate is added, formation of scale is a problem at high concentrations. A tertiary treatment of lime precipitation will fit the water for high concentrations. An improved biological treatment with high phosphate removal should be considered. For some waters this may obviate the need for lime treatment. The example studied is a water with a particularly high silica content necessitating lime treatment in any event. The treatment may be easier if the improved biological treatment is used.

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ACKNOWLEDGEMENTS

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WATER MANAGEMENT PLAN FOR A MIDWESTERN UTILITY

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INTRODUCTION

Ebasco Services Incorporated was engaged by a midwestern utility to perform engineering services for a 1200 MW coal-fired electric generating facility. In conjunction with the design of this generating station, Envirosphere Company, a division of Ebasco Services Incorporated, prepared a water management study. The purpose of this study was to optimize the use of plant water resources by using such water management techniques as water reuse and wastewater treatment to the extent necessary to comply with applicable federal and state regulations. This paper presents the water management plan developed for the station. The generalized flow diagram for plant water management is shown in Figure 1.

PLANT DESCRIPTION

The generating station will be located along the Ohio River and will be comprised of two 600 MW coal-fired units. Unit 1 is scheduled to go into operation by June, 1981, and Unit 2 by September, 1984.

The station is being designed to burn low sulfur coal and therefore no flue gas desulfurization is planned. Cyclic operation is planned for the station; that is, it is proposed to shut the plant down at nights. However, continuous operation is a future possibility. The water management plan presented is based on continuous full load operation since this would result in higher water flows.

PLANT WATER SUPPLY

The main water supply for the plant will be from a surface water intake on the Ohio River. The intake is of a submerged, slotted pipe design. The average two unit plant water use is estimated at 12,661 gpm. Surface water will supply all circulating water makeup and fire protection water.

Groundwater from deep wells will be used for demineralizer feed water, potable water needs, and other miscellaneous uses totaling an average of 197 gpm.

PLANT WATER DISCHARGES

Cooling Tower Blowdown

The recirculating condenser cooling system requires continuous makeup water to replenish water losses through drift and evaporation, and to replace blowdown required to maintain certain water quality parameters within desirable levels. The circulating water chemistry was analyzed in an effort to optimize the cycles of concentration in the cooling towers. Three cycles of concentration were determined to be the optimum. At this level, no chemical additions, except for chlorine, are anticipated and the concentrations of federally regulated constituents in the blowdown, namely zinc, phosphorus, and chromium, are kept well below the allowable limits.

As a part of the overall plant water reuse system, the makeup to the circulating cooling water is first utilized in a once-through system as cooling water for the auxiliary heat exchangers. The average flow of the auxiliary cooling water, and, therefore, the average makeup to the plant circulating cooling water system is 12,660 gpm. Based upon historical data, it is expected that during the months of July and August, when the auxiliary heat exchanger water requirements exceed the circulating cooling water system requirements, the cycles of concentration will be slightly lower than three.

The average blowdown from the circulating water system (that is, from the cooling towers) is expected to be 4,560 gpm. During plant shutdowns (cyclic mode of operation) the circulating cooling water system will not operate. However, the auxiliary heat exchangers will continue to operate. Blowdown during these periods will, therefore, be equal to the auxiliary cooling water requirements and will average 8,800 gpm.

Demineralizer Wastes

The water treatment system for the boiler feed will utilize two trains of cation-anion demineralizers, common degasifier, and mixed bed demineralizer with a design capacity of 680 gpm. The condensate polisher demineralizing system consists of deep bed type units.

The volume of regenerant wastes, including rinse water, is estimated at approximately 48,000 gallons per regeneration for two-unit operation. When the mixed bed demineralizer is regenerated, the total waste volume will be approximately 60,000 gallons. The demineralizer regeneration wastes are expected to average 15 gpm with a maximum flow of 340 gpm.

Fly Ash and Bottom Ash Transport Water

The fly ash collected at the electrostatic precipitators will be conveyed hydraulically to the fly ash storage pond. Bottom ash from the bottom ash hoppers will be conveyed hydraulically to the bottom ash storage pond. Ash sluicing will be on an intermittent basis. The average water requirement for fly ash transport is 1,458 gpm. For the bottom ash system, the average requirement will be 2,914 gpm, 1,730 gpm for ash transport and 1,184 gpm for cooling and sealing.

Sanitary Wastewater

The sanitary waste treatment facility will be designed for a staff of 300 persons. The flow is expected to average 10 gpm.

Boiler Blowdown

Boiler blowdown will be continuous and the total flow is estimated at 80 gpm.

Metal Cleaning Wastes

Metal cleaning wastes from boiler chemical cleaning will occur approximately once per three to five years per unit. The waste volume during this cleaning period is estimated to average 1,250,000 gallons. Metal cleaning wastes will include air preheater washes. Average flow is expected to be 1 gpm.

Miscellaneous Wastewater

Routine daily cleaning wastewater includes miscellaneous equipment cleaning, laboratory, sampling stream wastes, and floor drains. Average wastewater flow is expected to total 26 gpm, which includes routine testing of the fire protection system estimated at 1 gpm average.

Coal Storage and Contaminated Area Runoff

The proposed coal storage area for the station is approximately 40 acres including the reserved area. Maximum runoff is estimated at 2,175,000 gal/24 hour, or 1,500 gpm, using a coal storage area of 20 acres for two-unit operation and using the one-in-ten-year, 24-hour storm and 100 percent runoff. The average runoff, based on annual average rainfall is 45 gpm.

The contaminated runoff from the precipitator area is expected to average 5 gpm with a maximum of 150 gpm.

WATER QUALITY REGULATIONS

Federal Effluent Guidelines and Standards[1]

This plant is classified as an existing source, one for which construction began prior to March 4, 1974. The level of effluent control required is the "Best Available Technology Economically Achievable" (BATEA).

State Regulations

The state water quality regulations are in the process of being finalized. Regulations in the form of water quality standards for segments of the Ohio River are expected to be promulgated in the near future.

WATER MANAGEMENT PLAN

Due to the proposed cyclic operation of the plant, there was a potential for exceeding the existing state thermal standards as they were applied to the cooling tower blowdown if discharged directly to the river. In addition there was a potential for undesirable thermal stresses on the aquatic ecosystem due to the considerable changes anticipated in the blowdown temperature during a 24-hour period.

It was determined that by directing the cooling tower blowdown through one of the ash ponds before final discharge into the river, the potential problems would be eliminated. Once this was determined, a number of alternative flow schemes were identified and evaluated with respect to environmental acceptability, technical feasibility, operating efficiency, and cost effectiveness. The alternative selected is presented in Figure 1 and described below.

The influent sources of water are deep wells, the Ohio River, and rain water. The only point of discharge from the plant is the overflow from the fly ash pond. The water management plan incorporates a cleaning waste retention basin, a collection basin, the bottom ash pond, and the fly ash pond. All wastewater streams in the plant are directed to one of these basins or ponds, and eventually overflow from the fly ash pond as the final discharge. The water collected in the collection basin is directed to the bottom ash pond which overflows into the fly ash pond. The bottom ash pond is utilized as a source of water for reuse within the plant. Because of the long retention time provided in the ponds, the chemical and physical constituents of the final effluent are not expected to fluctuate significantly from day to day.

Federal EPA effluent limitations for the plant will be met by the application of BATEA. Compliance with state water quality standards are expected through the use of the allowable mixing zone.

DISCUSSION

In this section each major plant system is described and the water management features which will bring the effluent into compliance are outlined.

Sanitary Wastes

The sanitary waste treatment system will consist of an extended aeration package plant with aeration, sedimentation, chlorination, skimmer, and aerobic sludge digestion. The effluent will be directed to the bottom ash pond via the collection basin and is expected to average 10 gpm.

Makeup Demineralizers and Condensate Polisher Wastes

The wastes, averaging 15 gpm, will be directed to the bottom ash pond via the collection basin. The wastes will vary over a pH range of 2 to 12, are expected to be high in total dissolved solids, and may contain some suspended solids. Directing this waste to the ash ponds accomplishes flow equalization, neutralization, and sedimentation.

Boiler Blowdown

Boiler blowdown will be fairly continuous and will average 80 gpm. Estimated blowdown characteristics are as follows:

pH	- 9 to 9.5
NH_3 (as N)	- 0.3 to 1.1 mg/l
Total Dissolved Solids	- 1 to 10 mg/l
Iron	- less than 1 mg/l
Copper	- less than 1 mg/l

Normally, boiler blowdown will be directed to the bottom ash pond via the collection basin. In case the iron and/or copper concentration exceeds 1 mg/l, the boiler blowdown will be diverted to the cleaning wastes retention basin for iron and copper removal to concentrations of less than 1 mg/l.

Metal Cleaning Wastes

Periodic cleaning wastes from the boilers, air preheater, and reheat-superheat systems, are expected to be high in suspended solids, low pH, and may have iron and copper concentrations in excess of 1 mg/l. The average flow is expected to be 1 gpm. These wastes will be directed to the cleaning waste retention basin. A treatment facility will be utilized for iron and copper removal to concentrations of less than 1 mg/l, and the treated effluent will be directed to the bottom ash pond via the collection basin.

Miscellaneous Wastes

Miscellaneous wastes consist of equipment drains, floor drains, laboratory wastes, transformer area and oil storage area storm water wastes, and other miscellaneous wastes. These wastes may be high in suspended solids and may be contaminated with oil and grease. Miscellaneous wastes are intermittent in nature and are expected to average 26 gpm. These wastes will be treated for oil removal in oil-water separators, discharged to the collection basin, and transferred to the bottom ash pond which will act as a sedimentation basin. The oil-water separators will be designed to produce an effluent with average oil and grease concentrations of less than 15 mg/l.

Cooling Tower Blowdown

The circulating cooling water system is blown down from the cooling tower basin and is directed to the bottom ash pond. Wastes generated from the periodic cleaning of the cooling tower basin are also discharged to the bottom ash pond. These wastes are expected to average 4,560 gpm with a maximum of 21,680 gpm during periods when the main condenser cooling system is shut down. Directing cooling tower blowdown to the bottom ash pond will accomplish suspended solids removal and the decay of free available chlorine to insignificant levels.

Contaminated Storm Water Runoff

Contaminated storm water drainage from the coal storage and precipitator areas is expected to be high in suspended solids. The average flow is expected to be 50 gpm with a maximum of 1,650 gpm. This flow will be directed to the bottom ash pond via the collection basin. The ash ponds will act as sedimentation basins.

Bottom Ash Transport System

Except for an average of 6 gpm of groundwater required for pump bearings, water from the bottom ash pond is utilized for the bottom ash system. An average of 2,908 gpm is withdrawn from the bottom ash pond. The overflow and seal water, averaging 1,184 gpm, is directed to the bottom ash pond via the collection basin. The bottom ash transport water, averaging 1,730 gpm, is directed to the bottom ash pond. The bottom ash pond acts as a sedimentation basin where the bottom ash settles out and is stored. A portion of the water in the bottom ash pond is reused for ash sluicing while the remainder overflows into the fly ash pond.

Fly Ash Transport System

Fly ash is conveyed to the fly ash pond using water from the bottom ash pond. The average requirement is 1,458 gpm. The fly ash settles in the fly ash pond and is stored while the water overflows over the effluent weir for final discharge to the river. The effluent from the fly ash pond is expected to average 4,623 gpm with a suspended solids concentration of less than 30 mg/l.

Final Effluent

The pH of the effluent from the fly ash pond cannot be predicted at this time. A fly ash pond effluent study has therefore been recommended. If the results of the study show that the pH of the final effluent will be greater than nine or less than six, a neutralization facility will be constructed to treat the fly ash pond effluent prior to its discharge into the river.

With the possible exception of pH, as discussed, the effluent from the fly ash pond is expected to meet all applicable effluent limitations.

SUMMARY

A water management plan for a 1200 MW coal-fired electric generating facility on the Ohio River has been developed. The plan incorporates extensive water reuse and treatment of selected waste streams to comply with effluent limitations.

Concentrations of zinc, phosphorus, and chromium will be below the effluent limitations in the cooling tower blowdown which is directed to the bottom ash pond for reuse. Metal cleaning wastes will be treated for iron and copper removal prior to mixing with other waste streams. The sanitary wastes will be treated in an extended aeration plant and the miscellaneous waste streams which may be contaminated with oil and grease will be treated for oil and grease removal prior to discharge into the collection basin. Contaminated storm water drainage will also be directed to the collection basin. Suspended solids removal will be accomplished in the ash ponds. The final effluent from the fly ash pond will be neutralized if necessary. The plant effluent will comply with all existing regulations.

The water management plan is flexible and can be retrofitted to meet any future regulations. In case it is necessary to comply with more stringent regulations in the future, the final effluent can be reduced considerably by operating the cooling towers at higher cycles of concentration. The reduced effluent can then be treated to comply with the new regulations.

REFERENCE

1. "Effluent Guidelines and Standards - Steam Electric Power Generating Point Source Category". Code of Federal Regulations, Title 40, Part 423, October 8, 1974, as amended.

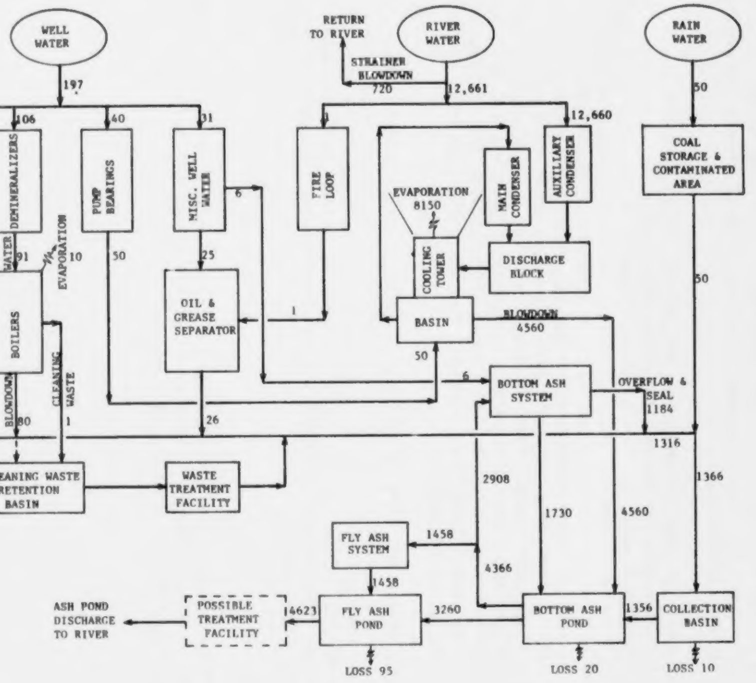

FIGURE 1. Plant Water Balance and Flow Diagram - Two 600 MW Units
(Numbers are annual flows in gallons per minute)

TOTAL WASTEWATER RECLAMATION AND REUSE AT McCLELLAN AIR FORCE BASE, CALIFORNIA

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Military bases and large manufacturing complexes are often excellent candidates for on-site wastewater reclamation. Reasons for this include:

- A large percentage of the fresh water supply is often used for non-potable purposes, i.e., cooling, air scrubbing, vehicle washing, irrigation, etc.
- There is often relatively close proximity of wastewater sources and potential user activities.
- Usually there exists a well controlled discrete area where public access can be limited and potential risks minimized.
- Such facilities have the capability to implement reuse systems relatively quickly compared to the lengthy procedures required for communities to go through many levels of regulatory agencies, public hearings, etc. for approvals and financing.

This is not to say that all, or even most, military bases can implement wastewater reuse in a cost-effective manner. Recent experience does indicate, however, that wastewater reclamation and reuse should be evaluated as part of the total analysis whenever future improvements to water or wastewater facilities are being contemplated. Dr. Stephen Shelton, in another paper being presented at this conference entitled "Wastewater Reuse Potential at Army Installations," discusses a current SCS Engineers project (3) which is developing a systems approach to making wastewater reuse evaluations and decisions.

This paper describes a major wastewater reclamation and reuse project designed by SCS Engineers for McClellan Air Force Base, California. The project is currently under construction and scheduled for completion in 1980. Among many interesting aspects are:

- The use of an extensive dual distribution system to transport the reclaimed water to over 40 separate locations where it will replace freshwater.

- The use of the reclaimed water for a variety of industrial type purposes.

- The reclamation and reuse of almost all base-generated wastewater is substantially cheaper than any of the other alternative wastewater treatment/disposal options investigated.

- Alternative designs which would reuse lesser percentages of the total base wastewater flow, i.e., 10 percent, 40 percent, etc., were also cost-effective. At many bases, total reuse will not be practical, but evaluation may still show beneficial potential reuse opportunities.

BACKGROUND

McClellan Air Force Base, located adjacent to Sacramento, California, is presently treating 0.8 mgd of domestic waste in one plant (STP) and 0.4 mgd of industrial waste in a second plant (IWTP). Both plants discharge to Magpie Creek, a tributary of the Sacramento River. The present National Pollutant Discharge Elimination Standards (NPDES) permit expires in 1979, and will not be renewed. McClellan Air Force Base had the following potential options for future wastewater management:

- Discharge wastewater instead to a regional system being implemented by Sacramento County;

- Dispose of its wastewater on the base;

- Reclaim and reuse wastewater for base activities; or

- Combinations of the above.

SCS Engineers was retained in July 1977 to investigate all alternatives for technical and cost feasibility, recommend the apparent best solution, and prepare a conceptual design of the recommended system. The final report (4) recommended the system described in this paper at an estimated capital cost of $2.8 million. By comparison, the connection to the county regional system entailed a connection charge of $4.6 million.

In June 1978, SCS Engineers was retained by the U.S. Army Corps of Engineers, Sacramento District, to prepare construction plans and specifications (2) for the project. Construction bids were taken in January 1979 and the low bidder of $2.7 million has begun construction.

FLOW VOLUMES

Reference is made to Figure 1, which depicts an overall base water hydraulic balance diagram. A study of this diagram shows that water supplies are the following:

- Line 1 - Freshwater to irrigation.
- Line 2 - Freshwater to domestic.
- Line 11 - Freshwater to industrial use.
- Line 16 - Rainy weather infiltration into the domestic sewerage collection system.
- Line 15 - Rainy weather infiltration into the industrial waste collection system.

Each of the above supply volumes varies from day-to-day, of course, but for analysis purposes the typical types of days shown in Table 1 are of interest; these are summer weekday (3.8 mgd), summer weekend day (2.1 mgd), winter weekday (3.1 mgd), winter weekend day (1.7 mgd), and rainy weekdays (2.2 mgd).

Again, returning to Figure 1, the hydraulic balance diagram shows that the fate of the water supplies are as follows:

- Line 4 - Influent to the sewage treatment plant (STP).
- Line 13 - Influent to the industrial waste treatment plant (IWTP).
- Lines 1 and 9 - Irrigation use.
- Line 3 - Evaporation and consumption - domestic.
- Line 12 - Evaporation loss from industrial activities, primarily cooling tower evaporation.
- Line 7 - Evaporation from storage - this is considered negligible in view of the accuracies involved in this analysis.

Each of the above discharges from the system varies from day-to-day, of course, but for analysis purposes the typical types of days shown in Table 2 are of interest; these are summer weekday, summer weekend day, winter weekday, winter weekend day, and rainy weekdays.

Summarizing Tables 1 and 2, and Figure 1, from a wastewater point of view, it can be seen that the approximate quantity of wastewater available for reuse purposes is the total of line 4 and line 13 in Figure 1, e.g., the influent volumes to the STP and the IWTP. This total water available for reuse is as follows, for typical days:

• Summer weekday	1.4 mgd
• Summer weekend day	1.1 mgd
• Winter weekday	1.3 mgd
• Winter weekend day	1.1 mgd

• Rainy weekday	1.7 mgd

Again, using Tables 1 and 2, and Figure 1, from a wastewater point of view, it can be seen that the theoretical amount of reclaimed water which can be consumed in a closed system is the irrigation total (not including base family housing), line 1, plus the industrial loss to evaporation, line 12. This total potential reclaimed water consumption potential is as follows for typical days:

• Summer weekday	1.8 mgd
• Summer weekend day	0.5 mgd
• Winter weekday	1.4 mgd
• Winter weekend day	0.3 mgd
• Rainy day	0.3 mgd

Combining the above reclaimed water available and reclaimed water equals 39 mil gal and the consumption equals 42 mil gal. Thus, the balance is favorable for total wastewater reuse during the summer months.

In a typical summer month, the supply of reclaimed water equals 39 mil gal and the consumption equals 42 mil gal. Thus, the balance is favorable for total wastewater reuse during the summer months.

In a typical winter month, the supply of reclaimed water equals 37 mil gal and the consumption equals 32 mil gal. Thus, a connection to the county is required to bleed off the difference of 5 mil gal/mo.

Assuming a winter month which has 15 rainy days, the supply of reclaimed water equals 43 mil gal and the consumption equals 21 mil gal, a difference of 22 mil gal. This discrepancy is covered by providing storage of 10 mil gal and a connection to the county of 0.5 mgd, or 15 mil gal/mo.

As a final step in the flow volume analysis, it is necessary to look at the individual industrial activities which comprise the reusers of reclaimed water. Table 3 lists these activities and their estimated reclaimed wastewater use during a typical summer month, and a typical winter month.

In summary, the analysis of water consumption on the base showed that existing non-potable industrial and irrigation (excluding housing areas) use exceeded the potential supply of reclaimed wastewater for much of the year. Note that by water consumption is meant sinks, e.g., the reclaimed water is lost from the system by evaporation and percolation.

WATER QUALITY

Through use of records, sampling, and analysis, an evaluation was made of existing freshwater quality (on-site wells), sewage treatment plant (STP) effluent, industrial waste treatment plant (IWTP) effluent, and effluent streams from various activities generating significant quantities of wastewater. Pilot tests were conducted with mixed media filters and various physical-chemical treatment processes to access the treatability of the wastewater effluents.

Winter weekend day	1.1 mgd
Rainy weekday	1.7 mgd

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Results showed that the existing treatment plants produced an excellent effluent, however, tertiary treatment was necessary to reduce suspended solids, turbidity, and phosphates (for cooling tower use). In addition, dual disinfection capacity was desirable to ensure the destruction of pathogens. Table 4 shows the expected reclaimed water quality when the full scale system is constructed.

The reclaimed water is of suitable quality for most sub-potable uses, including:

- Landscape and turf irrigation.
- Recirculating cooling systems, i.e., cooling towers.
- Cooling water on once-through systems, i.e., engine test cells, pre-flight engine testing, autoclaves, etc.
- Wet scrubbers for air emission control.
- Paint shop water walls.

The reclaimed water is also considered of suitable quality for sub-potable use with high potential for human contact, such as vehicle and aircraft washing, desealing operations, paint stripping, etc. It was decided at McClellan Air Force Base, however, not to use reclaimed water for these operations because the additional quantities consumed by these operations were relatively minor.

The reclaimed water was not considered of sufficiently high quality because of high dissolved solids concentrations to use for steam boiler makeup, photo processing, and metal plating shop rinse waters.

SYSTEM DESIGN

In 1976, SCS Engineers, under contract to the U.S. Air Force, developed a computer model for wastewater reuse (4) designed to aid engineers in the rapid simulation of alternate system configurations. The computer model allows the rapid comparison of alternate systems in terms of volumes reused, resulting water quality, storage required, pumping required, pipeline sizes and lengths, treatment processes, and estimated costs. The computer model was used to analyze potential alternate system configurations of McClellan Air Force Base and was of significant help in narrowing the final choices.

The final reuse system is designed to treat, store, pump and distribute reclaimed wastewater to on-base industrial and irrigation activities which can utilize sub-potable water in a cost-effective manner. The recommended system is the end result of an intensive analysis of alternative system configurations; an analysis which showed the recommended system superior.

The system design is shown conceptually in Figure 2. The system features reclaimed water connections to all the potential major base users of non-potable water. These users will easily utilize all the wastewater volume generated by the present sewage treatment plant (STP) and the industrial waste treatment plant (IWTP) during most of the year. During periods of heavy rainfall when reclaimed water demand is reduced, the system provides 10 mil gal storage and an 0.5 mgd connection to the Sacramento County Regional System as a means of bleeding off excess wastewater.

Additional treatment by mixed media filtration is provided in order to reduce suspended solids and turbidity. Filtration effluent is not considered an absolute necessity by the project team, however, it is considered desirable for aesthetic reasons and to prevent possible clogging of sprinkler heads in the irrigation systems. The STP effluent is given alum treatment to remove phosphorus and reduce silica, in order to improve water characteristics for cooling tower make-up water use. Both the IWTP and STP effluents are also additionally disinfected (chlorinated), in order to ensure bacterial destruction and reduce ammonia concentration. These additional treatment unit processes are located within the existing STP and IWTP sites, respectively.

Two major pump stations are included; one located at the IWTP and one at the STP. Both pump directly into the distribution system. The pump station, located at the STP site (designated A in this discussion), will pump continually at a rate of approximately 0.8 mgd, regardless of system volume demand. If system volume demand is less than a 0.8 mgd rate, the excess water will be automatically diverted into the long storage ponds located at the IWTP site. The other pump station, located at the IWTP site (designated B in this discussion), rides on the system, i.e., it changes its volume output to reflect changes in system volume demand. Volume is controlled by means of a pressure-sensitive control system.

The reclaimed water distribution system will include approximately nine miles of pipeline ranging in size from 12-inch to 2-inch diameter. Class 150 asbestos-cement pipe is used for sizes above 4 inches and Schedule 80 PVC pipe for sizes of 4 inches and below. Minimum pressure will be 40 psi. All pipe is wrapped with tape designating the contents as "non-potable wastewater." Similar permanent signs and tags are attached to all surface appurtenances so as to prevent future accidental cross-connections.

The wastewater reuse system is extensively controlled and monitored by electronic instrumentation. Continuous monitoring at a central control site is made of chlorine residual concentration, system pressure, pumping rates, volume in storage, and any failure alarm situations.

Obviously, it is not feasible in this paper to describe a $2.7 million system in detail. Interested readers are welcome to contact the authors at SCS Engineers, Long Beach, California, for additional details and copies of documents.

SYSTEM COST

The total estimated capital cost of the system is $2.8 million, not including contingencies and engineering.

The estimated annual operation and maintenance (O&M) cost of the recommended system is $129,000. This is the cost for the reclaimed water treatment, storage, and distribution system only. It does not include the cost of operating and maintaining the existing wastewater collection and treatment system.

A life cycle cost analysis was conducted for the recommended system and the major alternative solutions analyzed. Table 5 presents the cost summary. The system numbers shown in the left-hand column of the table are briefly described below.

The six alternatives can be summarized as follows:

1. This alternative assumes no reuse, no flow equalization, and direct discharge into the Sacramento Regional trunk line of the IWTP effluent and raw domestic sewage.

1a. This alternative is identical to No. 1 with the exception of short-term storage to level off peak daily flows.

2. Alternative No. 2 modifies Alternative 1a to include reuse of the plating shop and autoclave effluent for cooling tower make-up. This represents a reuse level of about 6 percent of the total base wastewater.

3. This system involves reuse of the STP effluent in major cooling towers and the autoclave. The IWTP effluent and remaining STP discharge are fed to the county regional system. This represents about a 50 percent reuse on a total system basis.

4. This network provides for total effluent reuse on base for irrigation and industrial uses. All excess wastewater not reused will be sprayed on land adjacent to the runways through sprinkler systems.

5. This is the recommended system. It features the same reuse patterns as No. 4 except that excess effluent is discharged to the county during off-peak periods.

A review of Table 5 shows that all the alternatives involving reuse had a cheaper life cycle cost than did

Alternatives 1 and 1a which involved no reuse. The two systems involving maximum reuse (Numbers 4 and 5) are far less costly than any of the other alternatives. The reader will note that Alternative 4 has a lower life cycle cost than does the final selected system. The difference results because the selected system has a "safety valve" connection to the county regional trunk sewer and system No. 4 does not. It was decided that the insurance provided by the connection to the county trunk sewer is worth much more than the additional cost of the connection.

ACKNOWLEDGMENTS

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2. "Design of Water Pollution Abatement at McClellan Air Force Base, California." Contract No. DACA05-78-C-0065, awarded by Sacramento District, Corps of Engineers, Sacramento, CA, to SCS Engineers, Long Beach, CA, Mar. 6, 1978. Final documents include Construction Plans, Specifications, Basis for Design and Design Calculations.

3. "Subpotable Water Reuse at Army Fixed Installations: A Systems Approach." Contract No. DAMD17-78-C-8080, awarded by U.S. Army Medical Research and Development Command, Fort Detrick, Frederick, MD, to SCS Engineers, Long Beach, CA, Oct. 1, 1978.

4. "Wastewater Management Alternatives and Reuse Study." Contract No. FO 4699-77-90068, awarded by McClellan AFB, CA, to SCS Engineers, Long Beach, CA, Jun., 1977.

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*None of the documents listed above are generally available. Persons interested in obtaining copies are requested to contact the awarding agency (see Acknowledgments) or SCS Engineers, Long Beach, CA (213) 426-9544.

TABLE 1. WATER SUPPLY VOLUMES FOR TYPICAL TYPES OF DAYS

Water use (refer to Figure 1)	Estimated daily volume in mgd				
	Summer weekday	Summer weekend day	Winter weekday	Winter weekend day	Rainy weekday
Line 1 - Fresh water to irrigation, not including lawn watering on base family housing area[1]	1.2	0	0.9	0	0
Line 2 - Fresh water to domestic, including lawn watering in base family housing area[1]	1.5	1.3	1.3	1.1	0.9
Line 11 - Fresh water to industrial use, including cooling	1.1	0.8	0.9	0.6	0.9
Line 16 - Infiltration into domestic sewage collection system	0	0	0	0	0.1
Line 15 - Infiltration into industrial waste collection system	0	0	0	0	0.3
Totals	3.8	2.1	3.1	1.7	2.2

(1) Lawn watering in base housing area is separated, because it is not planned to use reclaimed water for this purpose.

TABLE 2. WATER DISCHARGE AND CONSUMPTION FOR TYPICAL TYPES OF DAYS

Description (refer to Figure 1)	Volume in mgd				
	Summer weekday	Summer weekend day	Winter weekday	Winter weekend day	Rainy weekday
Line 4 - Influent to the STP	0.9	0.8	0.9	0.8	1.0
Line 13 - Influent to the IWTP	0.5	0.3	0.4	0.3	0.7
Line 1 + Line 9 - Irrigation use, not including base family housing	1.2	0	0.9	0	0
Line 3 - Domestic evaporation and consumption, including base family housing irrigation	0.6	0.5	0.4	0.3	0.1
Line 12 - Evaporation loss from industrial activities	0.6	0.5	0.5	0.3	0.3
Totals	3.8	2.1	3.1	1.7	2.2

TABLE 3. ESTIMATED MONTHLY RECLAIMED WATER USE AND WASTEWATER DISCHARGE FROM BASE ACTIVITIES INCLUDED IN THE REUSE SYSTEM

			Water required mil gal/mo.		Wastewater discharged mil gal/mo.	
			Summer	Winter	Summer	Winter
1.	PFET	Preflight engine test	0.3	0.3	neg.	neg.
2.	ETC	Engine test cells	1.3	1.3	neg.	neg.
3.	EXL	Experimental lab fume scrubbers	3.0	3.0	2.0	2.0
5.	REL	Research lab fume scrubbers	0.5	0.5	0.3	0.3
6.	PLAST	Plastic shop autoclaves	0.4	0.4	0.4	0.4
9.	COOL	Cooling towers	20.0	14.0	6.0	4.0
10.	IRR	Irrigation, not including base family housing	25.2	18.9	0.0	0.0
11.	SAND	Sandblast shop	0.2	0.2	0.2	0.2
12.	Others	Paint water walls	0.1	0.1	0.1	0.1
		Totals	51	39	9	7

TABLE 4. EXPECTED RECLAIMED WATER QUALITY
(mg/ℓ, except where noted)

Constituent	STP Effluent with alum treatment and filtration	IWTP Effluent with Filtration	Commingled Effluent for Reuse
BOD	7.0	20	11
COD	20	70	37
SS	8.0	20	11
TDS	359	1272	663
Cd	0.002	0.01	0.005
Cr	0.038	0.05	0.042
Cu	0.02	0.01	0.017
CN	0.098	0.05	0.082
Pb	0.036	0.01	0.027
Zn	0.053	0.01	0.10
B	0.59	0.20	0.46
P	0.5	0.50	0.50
TKN	7.0	5.0	6.33
NO_3-N	5.0	4.0	4.67
NH_4-N	1.0	1.0	1.0
Fe	0.20	0.08	0.16
Mn	0.014	0.03	0.02
Se	0.002	0.002	0.002
Hg	0.001	0.001	0.001
As	0.004	0.002	0.003
Ba	0.18	0.10	0.15
F	0.50	0.57	0.52
Na	38.4	36	37.6
PHNL	0.01	0.002	0.007
Ca	44	255	114
Ag	0.01	0.01	0.01
Coli (#/100 ml)	<20	<20	<20
Cl	58	52	56
Si	60	28	49

TABLE 5. LIFE CYCLE COSTS OF ALTERNATE SYSTEMS

System No.	Initial[2] Capital ($1,000)	Additional[2] Capital Added[1] In 4th Year ($1,000)	Initial Annual O&M ($1,000)	Additional O&M[1] Starting in 4th Year ($1,000)	Initial Annual Water Cost Savings ($1,000)	Net Present[3] Worth Life Cycle Cost ($1,000)
1	4843	1000	51	60	0	7561
1a	4102	1000	44	60	0	6851
2	3852[4]	950	50	56	6	6526
3	3166	600	134	40	22	6802
4	3273	0	136	0	56	4639
Rec.	2790	300	129	20	56	4877

[1] Before being inflated for later years or discounted to present worth

[2] Annualized capital recovery (equal payments) at a 7% interest rate will be applied

[3] Assumes zero salvage value at end of 30th year. Inflation rate is 8%. Discount rate is 10%. Labor and replacement part requirements increase at 1% per year.

[4] Based on system No. 1a

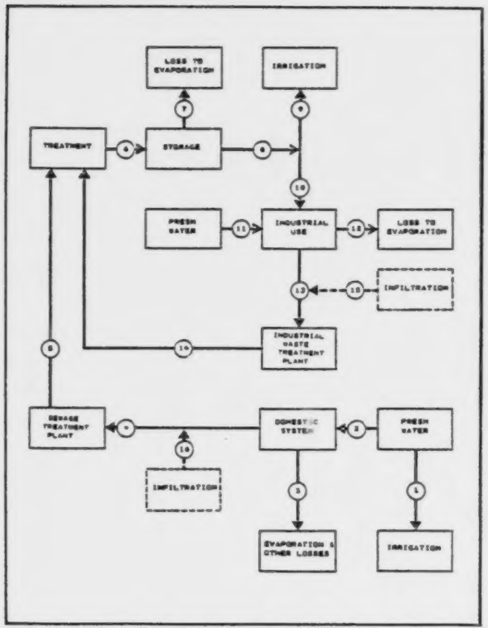

Figure 1. Water hydraulic balance diagram.

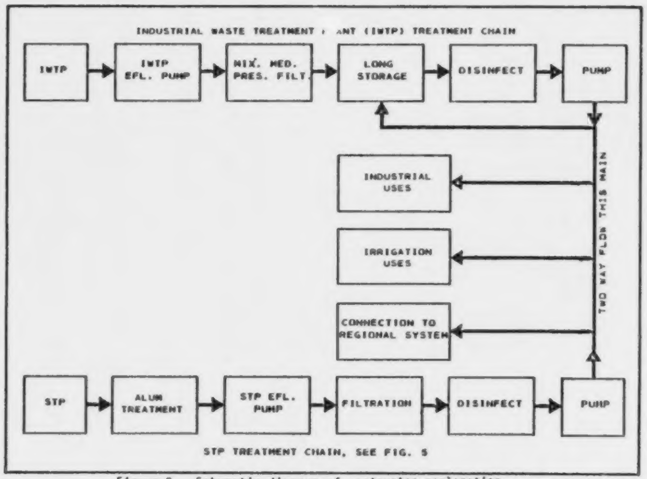

Figure 2. Schematic diagram of wastewater reclamation system at McClellan AFB, CA

WATER RECLAMATION AND REUSE IN THE POWER, PETROCHEMICAL PROCESSING, AND MINING INDUSTRIES

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Water has become a critical parameter to industry because of diminishing supplies, deteriorating quality, and government dictated effluent discharge limitations. To alleviate the shortage of this dwindling resource, various industries have begun purifying their wastewater to: 1) allow reuse and recycle, 2) decrease consumption of external supplies, 3) provide the utilization of previously unacceptable water sources, 4) remove pollutants prior to discharge, and 5) in some cases achieve zero discharge. This renovation of low quality supplies and wastewater has allowed various industries such as power generation, petrochemical processing, and the mining industries to maintain production and not be subject to curtailment of water and subsequent plant shutdown.

The diverse nature of the various types of wastewater which require treatment prior to reuse significantly affects the implementation of water reuse technology. Within each circumstance, various parameters such as: chemical engineering, existing and developing technology, economics, and end use of the reclaimed water is deliberated prior to the equipment being procured and placed on-line. In many cases, an efficient water treatment technology for reuse is unavailable and the alternatives are to develop a process for the one application or use a relatively inefficient method while paying the price but getting the job done quickly. The preference, primarily due to economics, is to attempt a developmental stage prior to any other activities then proceed with the approach which demonstrates operational feasibility.

Within this developmental stage, if it is opted, there is a gamble involved. This gamble is related to the actual development of an acceptable design, reliability of pilot tests, the relationship of prototype efficiency to full-scale efficiency, the variability of scale-up economics, and the capability of operators to maintain a novel and in some cases sophisticated system. In many cases, basic sciences must be utilized to acquire a feasible system and the only means by which to answer all process questions is to operate a prototype and learn from any mistakes. No system is designed the first time to completely account for all of the problems. The final system design should contain modifications which incorporate projected operation, unforeseen problems which surfaced, and data obtained during testing.

Most wastewaters generated from the power, petrochemical processing and mining industries can be reclaimed by the combination of existing technology with site specific modifications necessary to allow the existing technology to perform correctly. At least the wheel does not have to be reinvented, which is a great time savings. To realize the types of new modifications or areas which require development, a discussion of the water chemistry of specific industrial sectors will be of assistance.

POWER GENERATION. The primary water requirement in the power generation industry is associated with the use of boilers. The water (≈1 gallon per kwhr generated) which enters a boiler is converted with heat to the gaseous phase, and this steam is used to facilitate the operation of turbine generators. The water quality requirement for boiler make-up varies between high pressure and low pressure boilers but is generally high purity (<30 mg/L total dissolved solids) to eliminate scaling and is deaerated to circumvent corrosion. Because steam contains very few dissolved constituents, the boiler blowdown stream contains the bulk of the dissolved solids. The heat contained within the boiler blowdown is dissipated by the use of cooling towers.

The cooling towers use evaporative cooling to eliminate waste heat. The nature of the cooling tower blowdown is that it contains a high level of total dissolved solids (≈5,000 mg/L), is saturated with calcium sulfate, contains compounds which increase the efficiency of the cooling tower (i.e. chromates or polyelectrolytes), and has a high level of suspended solids (>50 NTU). In addition to the water used for boiler circuit, other effluents from a power plant include flue scrubber wash water, drains, saline solutions used in the regeneration of ion exchange demineralizers, and sewage.

The complexity of water reuse in this situation is obvious and must include considerations for salinity, saturated solutions, silica, suspended solids, and extreme upsets within the plant. Areas where water reuse can be applied: boiler make-up, NO_x and SO_2 scrubber make-up, cooling tower operations, turbine cooling injections, and potable sources for employees.

PETROCHEMICAL PROCESSING INDUSTRY. The petrochemical processing industry modifies raw hydrocarbons and other organics via heating, catalytic cracking, oxidation, chlorination, or polymerization to produce a finished and/or purified product. Water is used in this industry for steam generation via boilers, as a reaction medium, and as a coolant, in cooling towers, and in washing the products. The wastewater which is effluent from a petrochemical plant contains organic derivatives and carry-over, metals used to improve the efficiency of processes, salinity, as well as the normal constituents of cooling tower blowdown. Areas where water reuse is effective are: boiler make-up, process water, cooling water, cooling tower make-up, and product wash water.

MINING INDUSTRY. The mining industry utilizes water in most non-pyrogenic processes and in all hydrometallurgical processes. The water is used in: metal leaching, ore washing, floatation, as a process medium, boiler make-up, and concurrent with extraction-resin regeneration. Wastewater is generated by both the processes and mine dewatering. The wastewater which is obtained contains: toxic metals, trace metals, heavy metals, oxidants, reducing agents, various poisons, radionuclides, salinity and suspended solids. The sectors where water reuse is effective are: metal leaching solutions, ore washing, floatation, process water, and boiler make-up.

The technologies which are incorporated to facilitate water reuse and reclamation must be cost-effective methods and should not interfere with plant processes. The economics of any water purification process are directly related to the quantity of different units required to produce the desired water quality. Example: to purify a complex stream, one approach is to treat for each constituent, pre-filtration-precipitations-resin ion exchange-demineralization as opposed to treating a majority of the constituents by pre-filtration-reverse osmosis. The concept of simplicity has definite economic advantages. Therefore, an extensive amount of process engineering and assessment of similar situations will definitely aid in developing the most economic process.

However, the important aspect of a simplified approach is knowledge regarding the general capabilities of a given process within the requirements of a specific water reuse project. Cognizance of past performance, efficiency, economics and reliability greatly aid in developing a unified process for removing contaminants and subsequently reusing water. Also, the limitations of a given system are very important. A technology may show utility in a given application, but if the system is restrained due to limiting characteristics which are endogenous to the specific reuse project, the technology will not be appropriate.

WATER ANALYSIS. Another parameter which is very important concerning water reuse is: human health effects in water reclamation. The wastewater stream must be extensively analyzed for the presence of undesirable, toxic or carcinogenic compounds. If such compounds are present, emphasis must be placed on the treatment technology to assure asthetic and inherent water quality of the purified stream. An organization which specializes in a full range of analytical services is Controls for Environmental Pollution, Inc.* CEP, Inc. offers a full range of pesticides, microbiological, ecological, radiological, personal assay, and wastewater analysis. They also establish monitoring programs to meet the requirements of federal, state and local regulatory agencies.

REVERSE OSMOSIS. This is an established technology which

*Controls for Environmental Pollution, Inc. 1925 Rosina street, Santa Fe, New Mexico 87502.

retains extensive benefits regarding water reuse in that this technology will remove neutral plus anionic and cationic inorganic species, large organics, and radionuclides. Reverse osmosis incorporates an applied pressure greater than the solution inherent osmotic pressure (1000 mg/L = 10 psi) to force water to cross a semi-permeable membrane while the dissolved salts are significantly rejected. The bulk of the ions is contained in the brine. The membrane rejection of monovalent ions averages 96%, the rejection of divalent ions averages 98%, the rejection of large organics (>180 Daltons) is approximately 99%, and the rejection of trivalent ions averages +99% rejection. These rejections are independent of the charge be it positive or negative.

Reverse osmosis purification technology will remove numerous dissolved species, but the membrane will foul easily due to a build-up of suspended material, precipitation of salts (scaling), biological plugging, heavy metal precipitation, and colloids. A suspended solid is by definition, material which will not pass through a 0.45 micron filter. A reverse osmosis system requires a feedwater with a quality of <1.0 nephelometric turbidity units (NTU) or a silting density index (SDI) less than 4.0.

This pretreatment requirement for a reverse osmosis system is a critical factor in the applicability of this desalination technology to water reclamation. If the proper pretreatment is not used or is not functional, the membranes will foul, plug up, and cease to produce purified water. Hence, the developmental area of reverse osmosis implementation in water reclamation is the pretreatment package and the existing technology is reverse osmosis. The established technology of reverse osmosis is a methodology which has been used on a variety of wastewaters and operated with great success.

The limitations of reverse osmosis water recovery are: product water quality, sparingly soluble salts, and finally salinity of the brine. Product water quality is a limiting factor because as water recovery increases, the concentration of salts in the brine increase, subsequently more salt permeates the membrane, and the quality of purified water deteriorates. If too large an amount of purified water is removed by reverse osmosis, certain salts can exceed their solubility within an aqueous solution. The salts which are found to generally cause membrane scaling are: calcium carbonate, calcium sulfate, barium sulfate, and the oxides of iron and manganese. The final limiting factor of a reverse osmosis facility is the salinity of the effluent brine. As this salinity increases with water recovery, the level of dissolved solids counteract the applied pressure and the force of purification is decreased and finally nullified.

ASSESSING PRETREATMENT REQUIREMENTS. The quality of the wastewater to be treated must be assessed regarding: the presence of a fouling problem, the nature of the foulant(s), the quantity of fouling material, and the efficiency of the pretreatment system to remove this fouling material. Also, a consideration regarding fouling is a mode of membrane cleaning which will be effective in removing the foulant if it should collect on the membrane surface.

The presence of a fouling problem due to suspended material contained within a proposed feedwater to a reverse osmosis system can be detected in two ways: 1) a silting density index and 2) turbidity. A silting density index incorporates the use of a 0.45 micron filter such as the Gelman GN-6 filter* under conditions of constant pressure to measure the decrease of water flux across the filter due to suspended material. The filter (Figure 1) is placed within a holder and operated under a constant pressure of 30 psi. Precautions should be made to eliminate any air bubbles on the filter. These air bubbles can be removed by placing the apparatus, including membrane, in a verticle position, filling it with water from the effluent side and briskly tapping the filter holder.

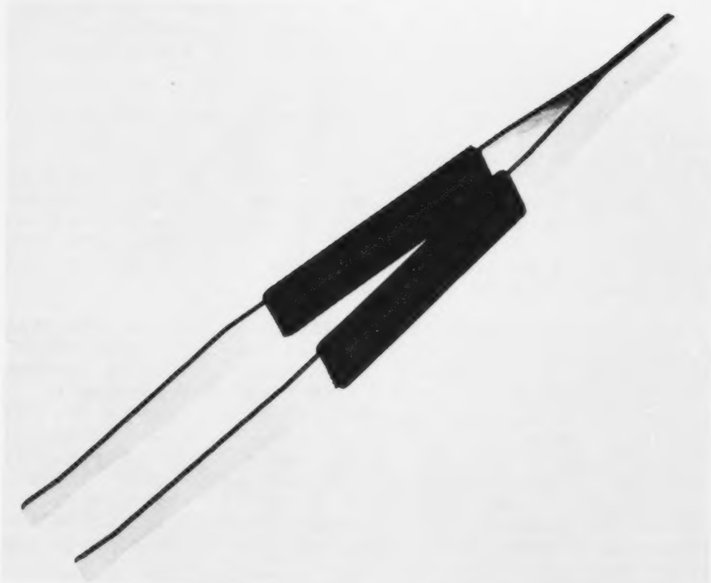
The stream to be treated by reverse osmosis has a silting density index (SDI) assessed by: 1) measuring the time period required for the first 500 ml of solution to pass through the GN-6 filter, 2) measuring the time period required for 500 ml of solution to pass through the filter after 15 minutes of operation, and 3) calculating an SDI. The SDI is calculated by subtracting the ratio of the first time period to the second time period from one and dividing this quantity by the total time period of the test. An SDI less than 4.0 is acceptable. It should be noted that the first time measurement should be greater than 15 seconds because a lower value designates incorrect operating pressure, a leak within the apparatus, or a malfunctioning filter.

Diligence should be observed with the filter when conducting an SDI test. A pair of clean forceps (Figure 2) should be used at all times to handle the filter. The use of bare fingers in handling the membrane may introduce dirt or grease on the surface of the filter and cause erroneous results because of a preferred path of flow on the surface of the filter. Also, the use of forceps circumvents the possibility of puncturing the filter during handling, which would also result in erroneous data.

To insure a range of consistancy within the wastewater stream to be reclaimed with reverse osmosis, numerous SDI tests should be conducted. These tests should be conducted with the stream being run at least four hours prior to analysis to eliminate suspended material inherent to the plumbing, remove biological activity due to the water being stagnant within the pipes, and flush out any material which is present because of the start-up itself. These tests should be run three times a day for three days to measure the fluctuation of suspended materials within the stream and statistically establish the extent of required pretreatment.

*Gelman Sciences, Inc. 600 S. Wagner Rd. Ann Arbor MI 48106

GN-6
SINGLE PACK
GELMAN
FILTRATION PRODUCTS
GELMAN
GELMAN



A silting density index should be conducted as a prerequisite to any membrane type desalination system. This test is very accurate when carefully done. The use of the naked eye to measure a given level of suspended material is NOT ACCURATE. When observing a sample by visual inspection, one must relate the level of suspended material with the cross section of membrane to be permeated with the quantity of water which crosses the membrane. A very difficult task indeed. Also, never take-for-granted a specified level of suspended solids. Upon finalization of the go-ahead on a project, the SDI should be re-assessed.

In many cases, regretfully that is, wastewater usually contains a level of suspended solids in excess of that which can be measured with a silting density index. The excessive levels will completely plug the filter and produce inaccurate results. The means of measuring the level of suspended solids used in this case is turbidity. Turbidity is a measure of the light deflection under a constant radius within a sample due to the endogenous level of suspended material. A nephelometric turbidity unit (NTU) is a standard quantity of light deflection as based upon a standard consisting of a formazin polymer. Turbidity does not quantify nor qualify the suspended material within the water, but establishes a relative level of light deflection. A general rule of thumb which may vary with wastewater is that in a turbidity range of 2 to 0, 15 SDI units approximately equal 1.0 NTU.

With the existence of a fouling problem due to suspended solids established via an SDI or turbidity test, the nature and quantity of the foulants must be investigated to designate the proper mode of pretreatment. The physical nature of the fouling material can be ascertained with the use of micronic filters having various nominal ratings. In utilizing such filters as manufactured by Gelman, the size of the particulate is known and hence the pretreatment requirements are ascertained. The types of Gelman micronic filters are listed in Table 1. The pore sizes, concerning assessment of particulate diameter range from 5.0 to 0.45 microns. If the suspended particulate is removed to the extent of an SDI less than 4.0 by a 5 micron filter (Figure 3), it is probable that a pretreatment sector using multi-media filtration will suffice.

Upon assessment of the raw feedwater particulate with a 3 micron filter, if the particulate crosses the test filter, it is suggested that multi-media filtration combined with a coagulant feed may remove the suspended solids. Any suspended particulate which crosses a 1.2 micron test filter may possibly be treated with the use of chemical feed and clarification followed by multi-media filtration and/or can be removed using ultrafiltration. The solids which cross a 0.8 micron rated filter can only be removed with ultrafiltration.

The chemical nature of the suspended solids can be analyzed by using the 0.45 micron filter. Using this micron rated filter to remove the fouling material will

TABLE 1

Various Micronic Test Filters to Assess Reverse Osmosis Pretreatment Requirements*

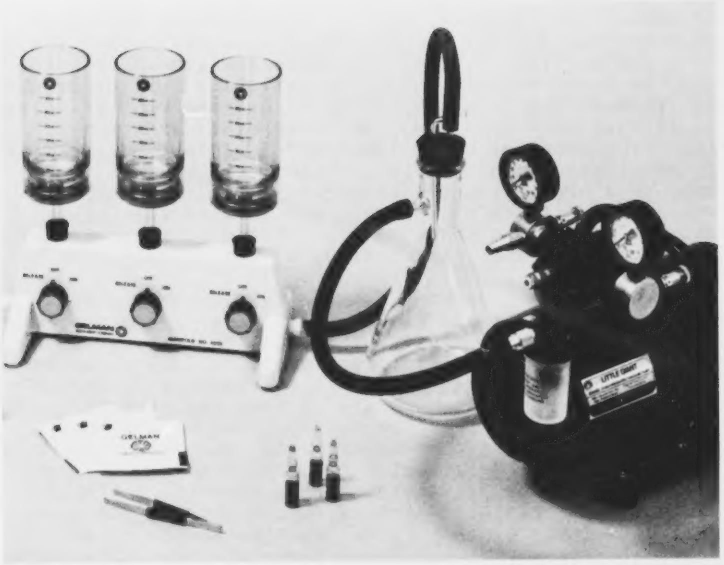
material	type	pore size(μ)	diameter(mm)	
metricel	GN-6	0.45	25,47	(47mm for SDI)
triacetate metricel	GA-1	5.0	90,142,293	
	GA-3	1.2	90,142,293	
	GA-4	0.8	90,142,293	
	GA-6	0.45	90,142,293	
teflon	TF-5000	5.0	90,142,293	
	TF-1000	1.0	90,142,293	
	TF-450	0.45	90,142,293	
acrylic copolymer	AN-3000	3.0	90,142,293	
	AN-1200	1.2	90,142,293	
	AN-800	0.8	90,142,293	
	AN-450	0.45	90,142,293	
cellulose	Alpha-1000	1.0	90,142,293	
	Alpha-450	0.45	90,142,293	
aromatic polymer	HT-650	0.65	90,142,293	
	HT-450	0.45	90,142,293	

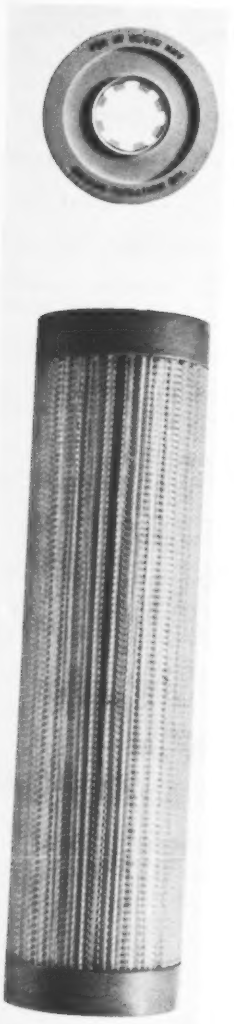
*Gelman Science Inc., 600 S. Wagner Road, Ann Arbor, MI 48106 result in the acquisition of material which can then be chemically analyzed. The chemical nature of the suspended particulate will determine the best mode of treatment technology required for the removal of this material. Using a filter holder in combination with a filter manifold and vacuum pump (Figure 4) results in an easily operated, convenient, apparatus by which to assess particulate size, acquire samples of particulate for chemical analysis, and quantify the level of suspended material.

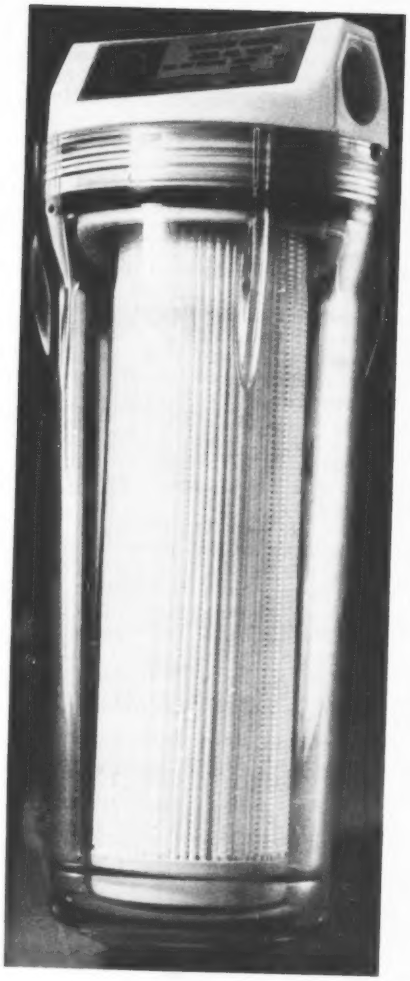
The quantity of suspended material which must be removed from the wastewater prior to reverse osmosis purfication designates the cyclic use of pretreatment equipment. The pretreatment equipment may be designed for 50, 70, or 90% of the feed stream and the number of units required in the overall package will be related to the quantity of solids to be removed. If the quantity of solids is large, more units with less capacity should be included so that while the majority are on-line, a small portion may be replenished or rejuvenated. The large number of units with a lower rated capacity allows greater flexibility. If the quantity of solids is small, a few large capacity units are appropriate because less time is required for rejuvenation, smaller fluctuations are probable, and it will be appropriate for a lower pretreatment expenditure to be acquired.

Utilizing the proper pretreatment for a reverse osmosis system as based upon an analysis of: the presence of a fouling problem, the nature of the foulant(s), and the quantity of fouling material, the efficiency of the pretreatment system can be measured and complimented by the use of cartridge micronic filtration. These cartridges are self contained (Figure 5) and are available in different micron ratings and the nominal rating used is reflective of the application. These cartridges are generally used after the pretreatment package as polishing filtration and their rate of use is an indicator of pretreatment efficiency. If excessive cartridges are used, this indicates design, equipment or operational difficulties. The polishing cartridges are also a safety factor in that if there should be a breakthrough within the pretreatment system, the micronic filters will impede the bulk of the breakthrough and accrue a cost savings related to minimal damage to equipment and less downtime of the plant.

In conclusion, reverse osmosis is a water purification technology which is effective in water reuse programs of the power generation, petrochemical, and mining industries. Reverse osmosis purification technology is economically effective because this desalination system can remove dissolved species which are charged and neutral--without a phase change. In order to apply the established technology of reverse osmosis as a tool for industrial water reuse and reclamation, a developmental phase is required to designate pretreatment requirements, applicability, limiting factors endogenous to the stream, the operational efficiency of the system, and the economics of operation. Presently, excellent means are available to


GELMAN
GELMAN
LITTLE GIANT





designate the extent of reverse osmosis pretreatment and the type of pretreatment technology which is required. This can be conducted using micronic test filters of various nominal pore sizes. Incorporating reverse osmosis with the proper pretreatment package has resulted in economic water reuse and reclamation within the industrial sector.

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REDUX^{tm} WATER RECYCLING SYSTEM

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St. Louis, Missouri

The Redux Corporation, a wholly owned subsidiary of Arundale, Inc., of St. Louis has been formed to engineer, manufacture and sell the Redux^{TM} water recycling system, a physical-chemical process which has been under development since 1974. Several models and prototypes have been built and tested to recycle laundry water in hospital, institutional and commercial laundries. In 1978, the first production model was placed in a commercial laundry in Boulder, Colorado. This system has been closely monitored for over six months to obtain data on operating cost, water quality and laundry product quality.

The success attained in recycling water from a commercial laundry has led to the evaluation and planned use of the Redux system to recycle gray water. The recycling of all "gray water" from a multi-family residential unit is one of the situations under consideration. Skin and eye irritation tests and ingestion tests have been conducted on laboratory animals using recycled water from the laundry. Some of the data is available at this time and is presented here. A search for water quality criteria by which to judge the process has led to the conclusions that overly conservative controls, based on theory rather than practice, are hampering the advancement of recycling technology. It is suggested that, after appropriate preliminary tests and where human ingestion is not planned, projects be initiated in which best practical (economically feasible) technology be utilized to recycle wastewater for human contact applications such as showering, that water quality be closely monitored and its actual impact on the end use be evaluated.

Water recycling has become a necessary part of the new age of resource conservation and environmental protection. In order to determine the adequacy of water treatment in a recycle process, much work has been done to determine which parameters should be monitored and what levels of contamination are acceptable as a function of end use. Since the difficult task of establishing water recycling standards has not yet been accomplished by government regulatory agencies, we have been required to make our own evaluation of acceptable standards.

All naturally occurring waters are contaminated to some degree. So-called pure water can be obtained only by very carefully controlled distillation processes and never occurs in natural rivers, reservoirs or even rain water. It has been necessary to examine water which is currently being consumed by populations around the world to see what levels of contamination are being endured. It is also important to note that many of the "contaminants" are beneficial. For example, pure distilled water is not pleasant to drink and it has been found that the addition of minerals (contaminants) improves the taste. On the other hand, in parts of the United States water from the municipal tap is not considered acceptable to drink because of a high mineral content and bottled water is utilized.

At Redux we are concerned, however, not in recycling water to drink but for use in commercial and institutional laundries and for bathing, cleaning and toilet flushing in the home. In most nations of the world, the public water supply is not used for drinking without first boiling or disinfection by the homeowner. Such water, however, is often used for bathing and laundry without further treatment.

The Redux Corporation has developed a water recycling system which is currently being used to recycle laundry water in commercial laundries. The recycled water has been analyzed and the data are shown elsewhere on this poster. Preliminary wash water standards as developed for NASA are likewise shown. The untreated wastewater from the commercial laundry in question should be much more polluted than water which we would expect to treat from home laundries, showers and wash basins. The major out-of-spec parameter as per the NASA study is in total dissolved solids and conductivity.

In parallel with our thus far unsuccessful search for published standards, we have adopted the policy of conducting laboratory tests to determine first-hand whether or not the recycled water taken from the Boulder B & M Laundry is acceptable for use in bathing and other home uses, excluding internal consumption. The first series were conducted by Raltech Scientific Services of St. Louis, Missouri, and involved the testing of rabbits for skin and eye irritation. The results, which were almost entirely negative, appear elsewhere on this poster.

Further testing is underway at Raltech's Madison, Wisconsin, laboratory and includes the LD-50 series which is utilized by the F.D.A., U.S.D.A., E.P.A., and health officials generally. The preliminary report on the LD-50 series is entirely negative. See Raltech letter dated March 14. Further subcutaneous skin irritation tests will be conducted on guinea pigs and patch tests are scheduled for skin sensitization on human subjects. The feeding study was conducted because some people, especially children, are apt to swallow some water while showering.

Another set of criteria which may be useful involves public swimming pools where even very small children are allowed to swim. Although this water is not recommended for drinking, almost every swimmer at one time or another swallows a mouthful of water. The criteria for swimming pools in Missouri, as an example, are appended. The essence of most swimming pool criteria is that if the water is sufficiently clear, is odorless, except possibly for chlorine, has an essentially neutral pH, and carries a residual of 1.5 ppm free chlorine, it is acceptable for bathing. This assumes, of course, that the water initially used to fill the pool was potable.

In summary, we submit the following comments on the use of recycled water for washing applications:

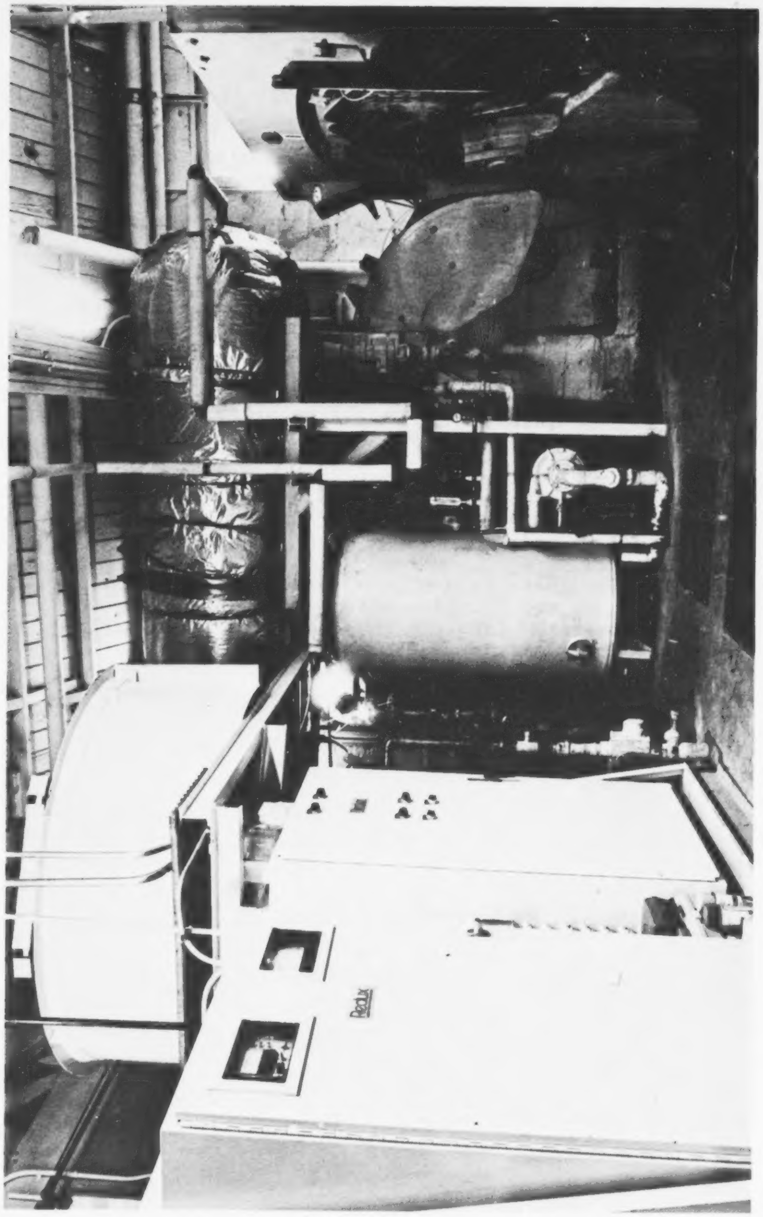
1. Recycled water even from a laundry can be acceptable as bath water.

2. Recycled water from home washing uses will be of better quality, e.g. have less salts or dissolved solids, than that from a commercial or industrial laundry.

3. A policy of testing each batch of water prior to use will ensure that residual chlorine has confined bacteria and viruses to acceptable levels.

4. Redux Corporation will continue the planned tests by Raltech Laboratories of its recycled water as regards skin irritation and other possible adverse effects to health.

5. Following installation of a residential system, testing of the recycled water should be continued by a qualified laboratory for an indefinite period to ensure that the water remains safe.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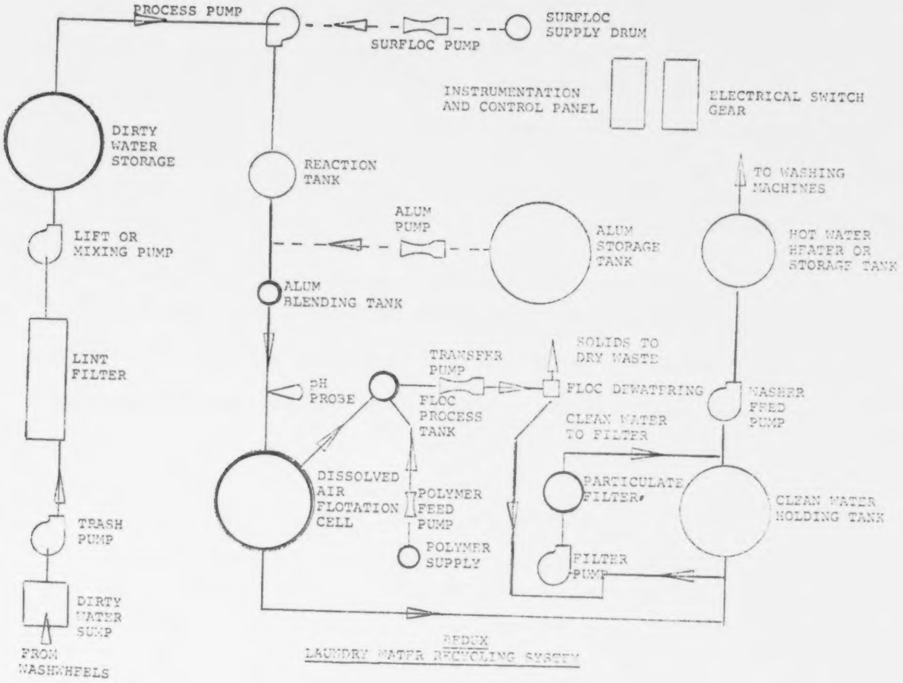


REDUX
LAUNDRY WATER RECYCLING SYSTEM

REDUX RECYCLE ECONOMICS AT BOULDER B & M LAUNDRY

OPERATING COSTS

CHEMICALS	(at $0.79/1,000 GALLONS)	= $23.46/DAY
POWER	(at $0.05/KWH)	= 2.97/DAY
	TOTAL COSTS	$26.43/DAY

OPERATING SAVINGS

WATER (81% RECYCLE AT $0.83/1,000 GALLONS)	$22.18/DAY
HEAT (AT $0.14/THERM)	30.17/DAY
TOTAL SAVINGS	$52.35/DAY

NET COST SAVINGS PER DAY $25.92 ($6,739/YEAR)

ANNUAL COST SAVING BASED ON DESIGN CAPACITY AND CURRENT WATER, SEWER, GAS, AND ELECTRICITY COSTS.

THE COST OF WATER & SEWER IN BOULDER IS ABOUT AVERAGE. THERE ARE MANY CITIES WITH COSTS ABOVE $2.00/GALLONS. THE TAP-ON FEES, HOWEVER, ARE AMONG THE HIGHEST IN THE NATION. FUEL COSTS IN BOULDER ARE ABOUT THE LOWEST IN THE NATION. ($.14/THERM)

SAVINGS IN CAPITAL EQUIPMENT COSTS

REPLACEMENT OF EXISTING BOILER TO HANDLE INCREASED WORK LOAD	$ 15,000
CITY TAP-ON FEE FOR LARGER WATER AND SEWER SERVICE	26,000
INSTALLATION OF LARGER WATER AND SEWER LINES	6,000
TOTAL CAPITAL EQUIPMENT SAVINGS	$ 47,000
COST OF REDUX SYSTEM	$ 60,000
ADDITIONAL CAPITAL COST TO RECYCLE	$ 13,000
COST SAVINGS PER YEAR	$ 6,739.20

A. AS WATER & SEWER RATES INCREASE AND FUEL COST INCREASE, SO WILL SAVINGS.

B. COST OF CHEMICALS IS PREDICTED TO INCREASE AT LESS THAN HALF THE COST OF FUEL AND WATER AND SEWER.

C. ROUTINE MAINTENANCE & OPERATION IS CURRENTLY REQUIRING LESS THAN 1 HOUR OF TIME PER WEEK.

D. TREATMENT COSTS ARE TYPICAL FOR LINEN LAUNDRIES WITH SOME INDUSTRIAL DISCOUNTS.

REPORT OF TESTS

WATER FROM B & M LAUNDRY-BOULDER,COLORADO

MATERIAL: Two (2) water samples identified Clean and Dirty

TESTS REQUESTED: Chemical analysis

RESULTS:

	Clean	Dirty
B.O.D., mg/l	44	435
C.O.D., mg/l	459	1853
Oil & grease, mg/l	8	211
pH	7.21	11.22
Chlorine, mg/l	0.04	0.05
Total Dissolved solids, mg/l	3268	3912
Total suspended solids, mg/l	31	167
Volatile dissolved solids, mg/l	202	777
Volatile suspended solids, mg/l	29	108
Mercury, mg/l	<.0005	0.0010
Cadmium, mg/l	<.01	0.03
Lead, mg/l	<.01	0.32
Sulfate Ion, mg/l	2180	1630
Arsenic, mg/l	<.05	<.05
Cyanide, mg/l	<.01	0.09
Phenol, mg/l	0.048	0.177
Carbonate, mg/l	<1	461
Silicate, mg/l	144	310
Calcium, mg/l	21	23
Iron, mg/l	0.11	0.75
Turbidity, JTU	9	270

	Clean	Dirty
Aluminum, mg/l ----------------	0.93	13.4
Nickel, mg/l ------------------	0.06	0.11
Zinc, mg/l --------------------	0.13	0.14
Total Chromium, mg/l ----------	0.10	0.09
T.O.C. mg/l -------------------	132	411
Copper, mg/l ------------------	0.14	0.43
Antimony, mg/l ----------------	<.10	<.10
Ammonia, mg/l -----------------	1.38	1.74
Nitrate, mg/l -----------------	0.46	2.5
Organic Nitrogen, mg/l --------	32	47
Sodium, mg/l ------------------	1065	1208
Magnesium, mg/l ---------------	3.4	1.5
Total Alkalinity, mg/l --------	76 as $CaCO_3$	848 as $CaCO_3$
Carbon dioxide, mg/l ----------	6.5	<.1
Barium, mg/l ------------------	<.05	<.05
Manganese, mg/l ---------------	0.01	0.03
Selenium, mg/l ----------------	<.01	0.11
Silver, mg/l ------------------	<.01	<.01
Total fixed solids, mg/l ------	3068	3194

REPORT OF ANALYSES

WATER SAMPLE RECD. 9-28-78

EYE IRRITATION

EYE REACTION	TIME (HR)	RABBIT NUMBER					
RABBIT WT. (G)		I 2164	II 2094	III 2271	IV 2304	V 2062	VI 1997
CORNEA	24	0	0	0	0	0	0
	48	0	0	0	0	0	0
	72	0	0	0	0	0	0
IRIS	24	0	0	0	0	0	0
	48	0	0	0	0	0	0
	72	0	0	0	0	0	0
CHEMOSIS	24	0	0	0	0	0	0
	48	0	0	0	0	0	0
	72	0	0	0	0	0	0
REDNESS	24	0	0	0	0	0	0
	48	0	0	0	0	0	0
	72	0	0	0	0	0	0

GRADES 1 TO 4 ARE ASSIGNED USING 4 TO DESIGNATE THE MOST SEVERE REACTION.

SKIN IRRITATION

SKIN REACTION RABBIT WT. (G) ERYTHEMA-ESCHAR	TIME (HR)	I 2571	II 2398	III 2448	IV 2571	V 2548	VI 2314	AVERAGE SCORE
INTACT	24	0	0	0	0	0	0	0.00
ABRADED	24	1	0	1	0	0	0	0.33
INTACT	72	0	0	0	0	0	0	0.00
ABRADED	72	0	0	0	0	0	0	0.00

SKIN IRRITATION

SKIN REACTION	TIME (HR)	I	II	III	IV	V	VI	AVERAGE SCORE
RABBIT WT. (G)		2571	2398	2448	2571	2548	2314	
ERYTHEMA-ESCHAR								
INTACT	96	0	0	0	0	0	0	0.00
ABRADED	96	0	0	0	0	0	0	0.00
								0.33 TOTAL
EDEMA								
INTACT	24	0	0	0	0	0	0	0.00
ABRADED	24	0	0	0	0	0	0	0.00
INTACT	72	0	0	0	0	0	0	0.00
ABRADED	72	0	0	0	0	0	0	0.00
INTACT	96	0	0	0	0	0	0	0.00
ABRADED	96	0	0	0	0	0	0	0.00
								0.00 TOTAL

PRIMARY IRRITATION SCORE = 0.1*

*NOTE: UNDER U.S. FEDERAL LAW ANY LIQUID WITH A SCORE OF 5.0 OR LESS IS DEEMED NON-IRRITANT.

TENTATIVE NASA STANDARDS FOR WASH WATER

PHYSICAL PARAMETERS	
COLOR, COBALT UNITS	≤ 15
CONDUCTANCE, SPECIFIC, UMHO-CM^{-1} AT 25°C	≤ 2000
FOAMING	NONPERSISTENT MORE THAN 15 SEC.
ODOR	NONOBJECTIONABLE
CHEMICAL CONSTITUENTS	
CARBON, TOTAL ORGANIC, mg/l	≤ 200
DETERGENTS	NOT SPECIFIED
LACTIC ACID, mg/l	≤ 50
NITROGEN, AMMONIA, mg/l	≤ 5.0
OXYGEN DEMAND, CHEMICAL, mg/l	NOT SPECIFIED
pH	5.0 to 7.5
SODIUM CHLORIDE, mg/l	≤ 1000
SOLIDS, DISSOLVED, AT 180°C, mg/l	≤ 1500
UREA, mg/l	≤ 50
MICROBIOLOGICAL	
MICRO-ORGANISMS, NUMBER PER ml, STANDARD 48 HR PLATE COUNT	≤ 10

STATE OF MISSOURI HEALTH REGULATIONS

SWIMMING POOL OPERATION

GENERAL - THIS CHAPTER CONTAINS THE WATER QUALITY REQUIREMENTS WHICH MUST BE MET, AND A LIST OF THE OPERATIONAL PRACTICES REQUIRED AT ALL PUBLIC BATHING PLACES.

WATER QUALITY - THE WATERS OF PUBLIC BATHING PLACES SHALL MEET THE FOLLOWING CHEMICAL, PHYSICAL AND BACTERIAL STANDARDS.

BACTERIOLOGICAL QUALITY - TO MEET DIVISION OF HEALTH BACTERIOLOGICAL STANDARDS, THE WATER IN THE POOL MUST CONFORM TO THE FOLLOWING:

(a) COLIFORM COLONIES FOR STANDARD SAMPLE SHALL NOT EXCEED 2.0 PER 100 MILLILITER.

(b) STAPHLOCOCCI ORGANISMS PER STANDARD SAMPLE SHALL NOT EXCEED 50 PER 100 MILLILITER.

(c) WHERE THE STANDARD PLATE COUNT IS USED, NOT MORE THAN 15% OF THE SAMPLES COVERING ANY CONSIDERABLE PERIOD OF TIME SHALL CONTAIN MORE THAN 200 BACTERIA PER MILLILITER, AS DETERMINED BY THE STANDARD (35°C) AGAR PLATE COUNT.

CHLORINE RESIDUAL - WHERE CHLORINE, HYPOCHLORITE, OR OTHER CHLORINE COMPOUNDS ARE USED FOR DISINFECTION, TESTS MUST BE MADE AS OFTEN AS IS NECESSARY TO MAINTAIN ADEQUATE RESIDUALS. A FREE CHLORINE RESIDUAL OF AT LEAST 0.6 ppm SHALL BE MAINTAINED THROUGHOUT THE POOL. IF CYANURIC ACID OR CHLORINATED ISOCYANURATES ARE USED, THE FOLLOWING ADDITIONAL REQUIREMENTS SHALL BE MET:

(a) A CYANURIC ACID TEST KIT SHALL BE PROVIDED.

(b) THE CYANURIC ACID LEVEL IN THE POOL SHALL BE KEPT BELOW 100 ppm.

(c) A FREE CHLORINE RESIDUAL OF AT LEAST 1.5 ppm SHALL BE MAINTAINED THROUGHOUT THE POOL.

pH - HYDROGEN-ION (pH) TESTS SHALL BE MADE AS OFTEN AS NECESSARY TO MAINTAIN THE pH AT A SATISFACTORY LEVEL. A pH OF 7.2 to 7.8 SHALL BE MAINTAINED.

CLEARNESS - THE WATER SHALL HAVE SUFFICIENT CLARITY AT ALL TIMES SO THAT A BLACK DISC, SIX INCHES IN DIAMETER, ON A WHITE FIELD IS READILY VISIBLE AT THE DEEPEST POINT OF THE POOL.

Raltech
SCIENTIFIC SERVICES, INC.

March 14, 1979

Mr. Robert Claunch
The Redux Corporation
1173 Reco Drive
St. Louis MO 63126

Dear Mr. Claunch

The Oral LD_{50} toxicity test was performed on the recycled wash water which was sampled for you by a representative of Ralston Purina. The results indicate, by definition in both EPA and FHSLA Regulations, that this product is NON-TOXIC; i.e., at 5 milliliters of sample per kilogram of body weight, no deaths occurred.

This report is an interim report. The final report will be issued along with the final report of the results of the Human Dermatological Patch Study which is scheduled to begin at the end of March.

If any questions arise, please do not hesitate to call.

Sincerely

John A. Kerzan

John A. Kerzan
Client Service

JAK/gh

P.O. Box 7545
Madison, Wisconsin 53707
608/241-4471
A Subsidiary of Ralston Purina Company

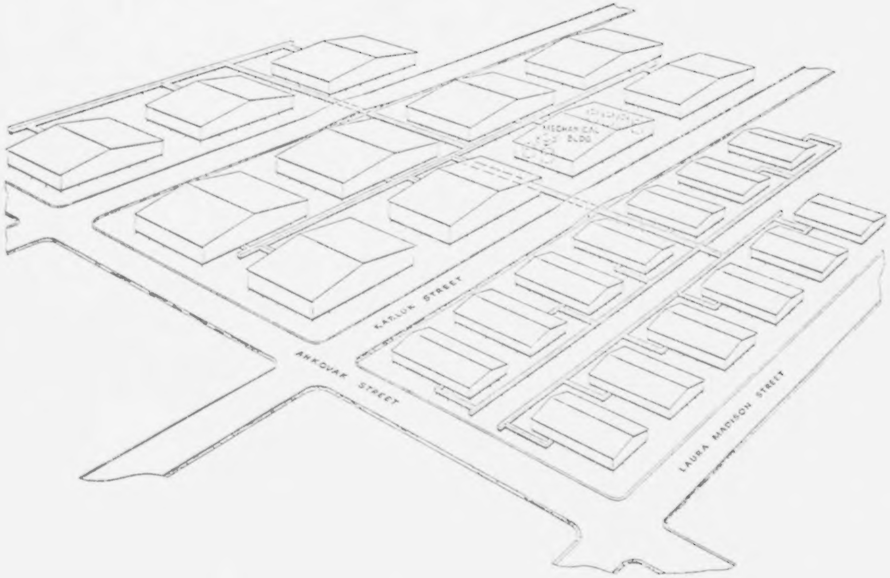
RT 4455

BROWERVILLE SUBDIVISION

WATER AND SEWAGE HANDLING SYSTEMS

FOR

BLACKSTOCK HOMES HOUSING ADDITION



THE REQUIREMENTS

- ELIMINATE DISCHARGE OF WASTE WATER ON THE GROUND
- REDUCE THE NUMBER OF FRESH WATER DELIVERY AND WASTE WATER COLLECTION POINTS
- PROVIDE A CENTRAL BUILDING WHICH WOULD INCLUDE SPACE FOR COMMUNITY USE
- KEEP INITIAL AND OPERATING COSTS AS LOW AS POSSIBLE
- WATER USED IN RESIDENCES MUST NOT GIVE OFF OFFENSIVE ODORS

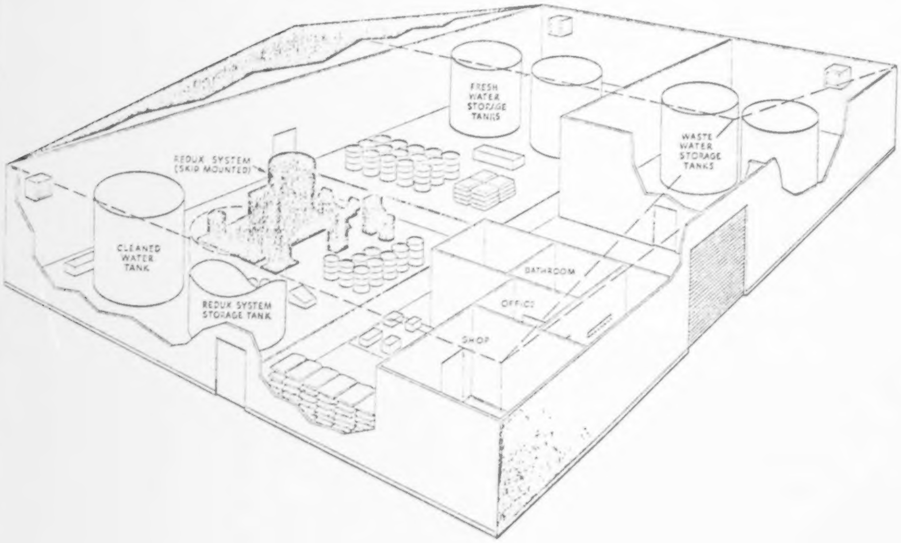
THE CONCEPT

- PROVIDE A CENTRAL BUILDING TO HOUSE WATER AND SEWAGE EQUIPMENT
- CENTRAL BUILDING WILL HAVE EXTRA SPACE FOR COMMUNITY USE
- PROVIDE A UTILIDOR SYSTEM TO INDIVIDUAL BUILDINGS IN THE ADDITION
- USE FRESH WATER IN SINKS AND LAVATORIES
- USE CLEANED WATER IN SHOWERS AND LAUNDRIES
- DO NOT RECYCLE FLUSH WATER FROM TOILETS,THUS ELIMINATING THE PRIMARY SOURCE OF ODORS

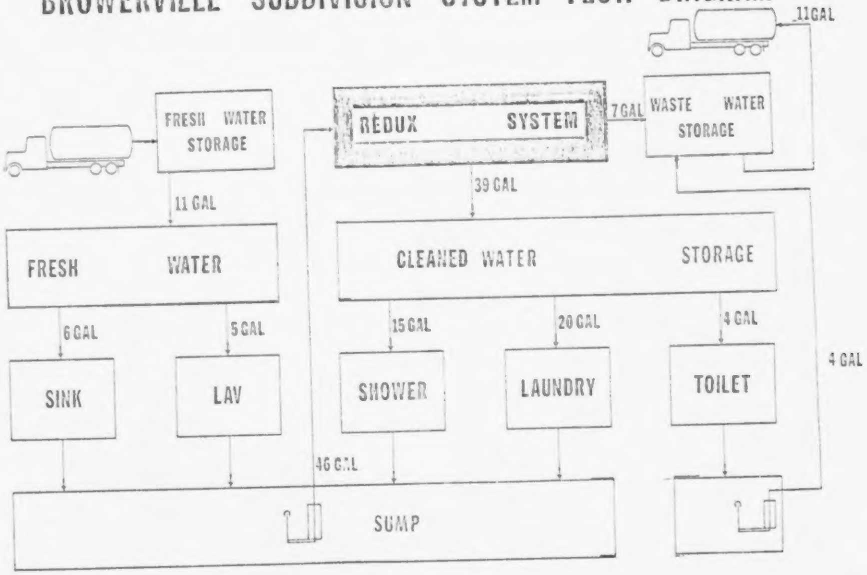
CLEANING (REDUX) SYSTEM

- PACKAGE SYSTEM; ONE SUPPLIER RESPONSIBLE FOR SYSTEM
- NO NEW TECHNOLOGY; PROCESSES HAVE BEEN PROVEN
- MAJOR TREATMENT STEPS INCLUDE:
    - COARSE SCREENING
    - CHEMICAL ADDITION AND MIXING FOR COAGULATION
    - SEPARATION OF SOLIDS; TOP AND BOTTOM OF TANK
    - FINAL FILTERING
    - CHLORINATION

BROWERVILLE SUBDIVISION
CENTRAL BUILDING


FRESH WATER STORAGE TANKS
WASTE WATER STORAGE TANKS
REDUX SYSTEM (SKID MOUNTED)
CLEANED WATER TANK
REDUX SYSTEM STORAGE TANK
BATHROOM
OFFICE
SHOP

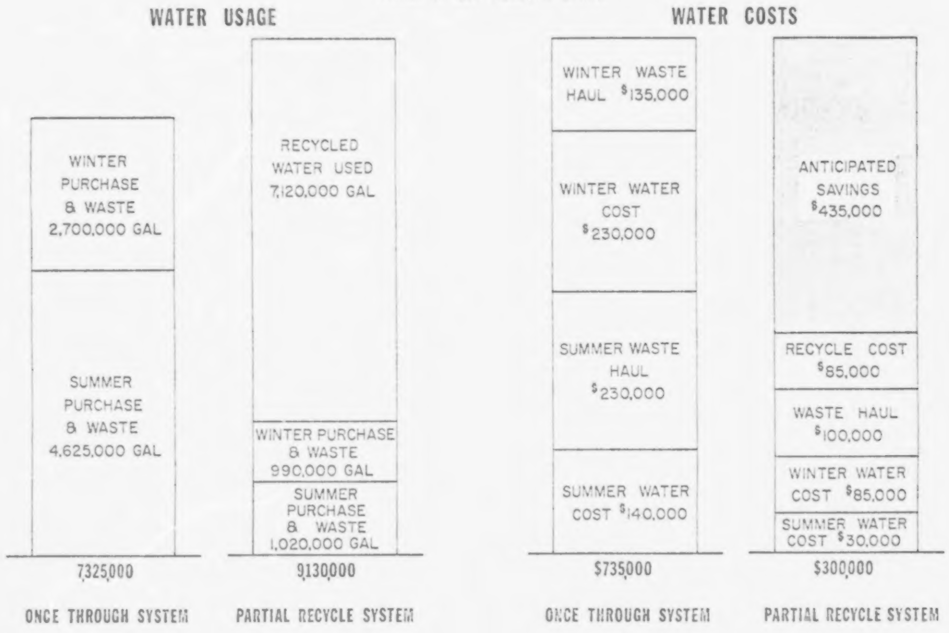
BROWERVILLE SUBDIVISION SYSTEM FLOW DIAGRAM



SECOND IMPROVEMENT

BROWERVILLE SUBDIVISION COST COMPARISON

BASED ON 500 PERSONS USAGE



INDUSTRIAL WASTEWATER RECYCLE/REUSE TECHNOLOGY

Ronald J. Turner
Project Officer
Environmental Protection Agency

Edwin F. Abrams
Operations Manager, Engineering Technology Division
Versar, Inc.

Edwin F. Rissmann
Chief, Industrial Pollution Control Branch
Versar, Inc.

Chia-Soon Ku
Senior Chemical Engineer, Industrial Pollution Control Branch
Versar, Inc.

INTRODUCTION

The Environmental Protection Agency has undertaken this project to assist industry and water resources managers to conserve water use while minimizing the discharge of hazardous pollutants through waterborne media. It has become increasingly apparent that many industries can only achieve these goals by applying improved wastewater recycle/reuse technology; however, EPA has recognized that to date utilization of technological advances has been limited to isolated cases and that no concentrated effort has been directed toward the development of a comprehensive data base from which industry and water planners can obtain guidelines.

This paper represents research findings on the current state-of-the-art of water recycle/reuse technology. When the entire project is completed, it should identify:

- Where current recycle/reuse technologies are being used
- Which industries are now using these technologies
- How each technology is presently limited and how future research and development funds should be allocated to fill gaps in the knowledge.

The final report will specifically provide:

- Detailed bibliography of water recycle/reuse technology for selected industries
- Tabulation and in-depth analysis of applications of novel technological approaches in use within these industries
- Discussion of the possibilities of technology transfer within or between industries

Table 1 presents an overview of the project goals. The remainder of the paper will explain how industries were selected, how research is being conducted, and what data have been identified and analyzed. Finally, there are descriptions of three companies' use of effective but highly varied methods of water recycle/reuse technology.

The project is now almost 50 percent completed. The final report, which is scheduled for publication in June, will most likely be available through the National Technical Information Service (NTIS), Springfield, Virginia.

SELECTION OF INDUSTRIES

Four criteria were used to select industries for inclusion in this study:

- High process water usage.
- Toxic content of the wastewater.
- Potential for recovery of useful products from wastewater.
- Growth potential of the industries.

Through use of these criteria, 39 industries were selected. These are identified in Table 2 along with the number of case studies found thus far in each.

Criterion 1

Industries with a high level of water use were an obvious choice for study since they afford an opportunity for the greatest overall reduction in water discharge. An example of this type of industry is pulp and paper manufacturing.

Criterion 2

Industries with effluents containing dissolved toxic materials were selected because reduction of these pollutants is a national priority. An example of this type of industry is one which manufactures certain organic or inorganic chemical products.

Criterion 3

Industries with potential for a high rate of resource recovery and reuse opportunities were selected because of the direct economic benefits recycling could produce in addition to conserving water supplies. An example of this type of industry is photographic processing.

Criterion 4

Although no industry was selected solely for its growth potential, it was recognized that national demand was increasing for the products and/or services of most industries included.

SEARCH METHODOLOGY

A literature search is being completed in each of the 39 industrial areas, and an overview of the methodology used to perform this task appears in Table 3. Currently, each reference is being thoroughly examined to determine whether it is relevant and whether it contains information from which case studies can be compiled.

All pertinent data will be assembled into a detailed water recycle/reuse bibliography on an industry-by-industry basis. The bibliography will further provide a breakdown by specific processes to determine where recycling/reuse technology is in use and in which areas technology transfer is feasible, either within the same industry or to other industries.

RESULTS

With the project approximately 50 percent completed, the following results have been achieved:

1. Over 1,000 references have been scanned.
2. Using information gathered from the references, categories of water recycle/reuse technology have been developed and cross-tabulated according to the type of industry in which they are used.
3. Over 75 case histories involving water recycling/reuse have been identified in the industries of interest. These include:

   a. A new pulp and paper production process which is not only effluent free but also more energy and materials efficient;
   b. The development and commercialization of several processes which reuse spent plating solutions and recover metal wastes for resmelting and sale;
   c. Examples of water reuse in some segments of the steel and petroleum industries which include a number of examples of materials recovery;
   d. The introduction of zero discharge processes for facilities processing photographic film and paper;
   e. The development of new technology which incorporates total water reuse in the production of such inorganic chemicals as hydrofluoric acid, aluminum sulfate and phosphoric acid; and
   f. The elimination or recovery of hazardous wastes from inorganic chemicals production, including recovery of phosphorous from phossy water wastes, mercury from mercury cell brine sludges and barium sulfate from diaphragm cell brine sludges.

DISCUSSION

To illustrate the type of technical material being analyzed in the project, three brief case histories, one from each of the three basic criteria mentioned previously, are now presented.

High Water Use - Closed-Cycle Bleached Kraft Pulp Mill System

A high level of water use is inherent in the manufacture of pulp or paper products. In the early 1970's Professor W. H. Rapson of the University of Toronto discovered a method using recycled water almost exclusively in a closed-cycle system.[1] The first mill to adopt this new technology was the Great Lakes Paper Co. in Thunder Bay, Ontario, in 1976 and, since that time, other plants have been constructed in the United States, Japan, Canada, New Zealand and Finland, which use at least part of this technology. A schematic of the new process is shown in Figure 1. The basic principle is that if the wood room of a pulp mill can operate completely on recycled water, the mill will discharge no pollutants into the environment. To accomplish this, accumulated suspended solids must be settled, filtered or centrifuged out and burned or buried. The closed pressurized brown stock screening system will then use only recycled filtrate. Since the unbleached pulp is washed entirely by continuous diffusion, there are no air-water interfaces to produce foam. The amounts of water used to wash the pulp are further sharply decreased by countercurrent washing and by recycling the chlorination filtrate, which dilutes the unbleached pulp as it enters the system. Perhaps the most novel feature of the process is the substitution of chlorine dioxide for chlorine in 70 percent of the bleaching. This substitution results in a product of improved strength, texture and color stability and also reduces the amounts of other wastes produced. The sodium chloride recovered from the process can be used onsite to produce sodium chlorate, an intermediate in chlorine dioxide production. Likewise, sodium sulfate and soda ash can be recovered from other process streams and entirely reused in operations.

Effluent with Dissolved Toxic Material - Settling Pond Recycle/Reuse System

In 1973 Allied Chemical modified the wastewater handling system at its hydrofluoric acid manufacturing plant in Nitro, West Virginia, to totally recycle water used in the wet scrubbers and in the gypsum transport system.[2] Figure 2 is a flowchart describing this process, which has proven highly successful. In general, sulfuric acid and fluorspar ore are reacted in a furnace to yield hydrogen fluoride gas and a solid calcium sulfate (gypsum). The gaseous hydrogen fluoride is condensed, purified and sold. The residue slurry and scrubbed effluent are neutralized and clarified in settling ponds, and water is recycled to the process for residue transport and/or wet scrubbing. The waste gypsum is recovered from the settling ponds and is sold as a construction material.

Resource Recovery - Zero Discharge System

In 1977 PCA International, a color photographic processing company, introduced new technology at its Matthews, North Carolina, facility through which 75 percent of all process chemicals are recovered and 90 percent of all wash water is recycled.[3,4] Figure 3 illustrates how the system works. Process wash water is collected and pumped through reverse osmosis units. These remove dissolved solids from 90 percent of the wash water, which is then available for immediate reuse. The concentrates from the reverse osmosis units are passed to a staged evaporation unit. Water from the evaporator is condensed, passed through an ion exchange process to remove ammonia, and is then available for reuse.

As the water is recycled, process chemicals are also treated and reused. In fact, seven of the 11 processing solutions involved are either partially or totally recycled. Included in the process is a method of regenerating bleach by treating spent ferric EDTA bleach with ozone. This causes the oxidation of the bleach without introducing other materials which could interfere with the photographic development process.

A final benefit of the PCA system is that whatever sludge remains from the recycling process is sent to a refinery where silver is recovered and resmelted.

CONCLUSIONS

The technology of conservation is relatively new but, as more water resources are depleted and more mandatory and voluntary regulations are developed to control their use, it will be an increasingly important field. The Environmental Protection Agency is currently striving to address one aspect of the problem by obtaining all available information on successful developments in the field of water reuse, by determining where these innovations can be applied in other areas, and in identifying gaps in the knowledge which, once filled, could contribute meaningfully to the preservation of the nation's hydrological resources.

REFERENCES

[1] RAPSON, W. H., "The Closed-Cycle Bleached Kraft Pulp Mill", Chemical Engineering Progress, 72(6), 68, 1976.

[2] REITER, W. M. and W. F. STOCKER, "In Plant Waste Abatement", Chemical Engineering Progress, 70(1), 55, 1974.

[3] DAIGNAULT, L. G., "Pollution Control in the Photoprocessing Industry Through Regeneration and Reuse", Journal of Applied Engineering, 3(2), 93, 1977.

[4] DAIGNAULT, L. G. et. al., "A Zero Discharge Wastewater Treatment System", Environmental Science and Technology, 12(9), 1004, 1978.

TABLE 1

GOALS OF THE PROJECT

- Detailed knowledge of what has been achieved in the water reuse area in 39 selected industries.
- Detailed information on actual wastewater recycle/reuse projects within these industries.
- Detailed information on where technology transfers can be made within these priority industries.
- Detailed delineation of future allocation of monies to develop new water reuse technologies.
- Detailed delineation of problem areas within the industries with regard to wastewater treatment and reuse.
- Detailed understanding of how process water needs of a number of critical industries can be minimized by the use of economical recycle/reuse technology.

TABLE 2

INDUSTRIES SELECTED FOR STUDY IN THE PROJECT

	Industry	*Number of Available Case Studies
1.	Adhesives and Sealants	0
2.	Aluminum Forming	1
3.	Auto and Other Laundries	9
4.	Battery Manufacturing	1
5.	Carbon Black	0
6.	Coal Mining	1
7.	Coil Coating	1
8.	Copper Forming	0
9.	Electroplating	7
10.	Electrical and Electronic Products	3
11.	Explosives Manufacturing	0
12.	Foundries	1
13.	Gum and Wood Chemicals	1
14.	Inorganic Chemicals	7
15.	Iron and Steel Manufacturing	4
16.	Leather Tanning and Finishing	2
17.	Mechanical Products	1
18.	Nonferrous Metals	1
19.	Ore Mining	2
20.	Organic Chemicals	2
21.	Paint and Ink Formulation	0
22.	Paving and Roofing	0
23.	Pesticide Manufacturing	0
24.	Petroleum Refining	4
25.	Pharmaceutical Manufacturing	0
26.	Photographic Equipment and Supplies	0
27.	Photographic Processing	4
28.	Plastic and Synthetic Materials	4
29.	Plastic Processing	0
30.	Porcelain Enameling	0
31.	Printing and Publishing	0
32.	Pulp and Paper	7
33.	Rubber	1
34.	Shipbuilding	0
35.	Soaps and Detergents	0
36.	Steam Electric	1
37.	Textile Mills	1
38.	Timber Products Processing	0
39.	Food and Kindred Products	5

* The number of case studies refers to the number of plant locations at which a water recycle/reuse or resource recovery technology is used.

TABLE 3

OVERALL SEARCH METHODOLOGY

A. Initial Literature Search

  1. Computer Search

    a. NTIS
    b. Chemical Abstracts Condensation/Gas
    c. Enviroline
    d. Pollution Abstract
    e. Other

  2. Library Search

    a. Chemical Abstracts
    b. Engineering Index
    c. Applied Science and Technology Index, Inc.

  3. Industries and Government Communications

B. Case History Studies

  1. Data analysis for each case
  2. Compilation of detailed case history data
  3. Telephone and letter contacts with plants to determine current project status

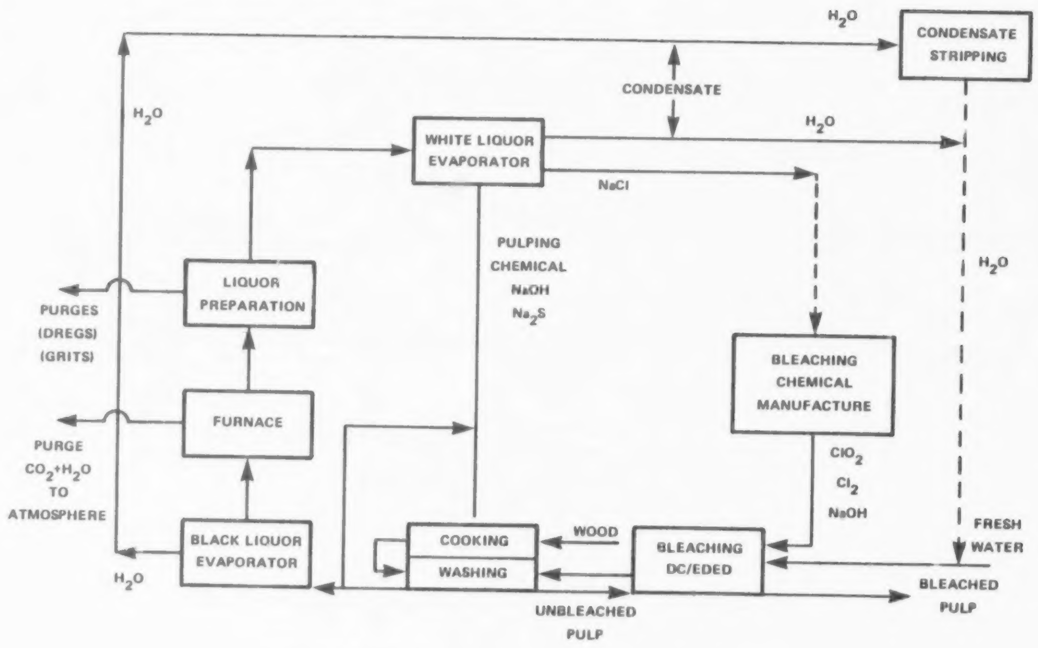


FIGURE 1 CLOSED-CYCLE BLEACHED KRAFT PULP MILL SYSTEM

GREAT NORTHERN PAPER COMPANY
THUNDER BAY, ONTARIO

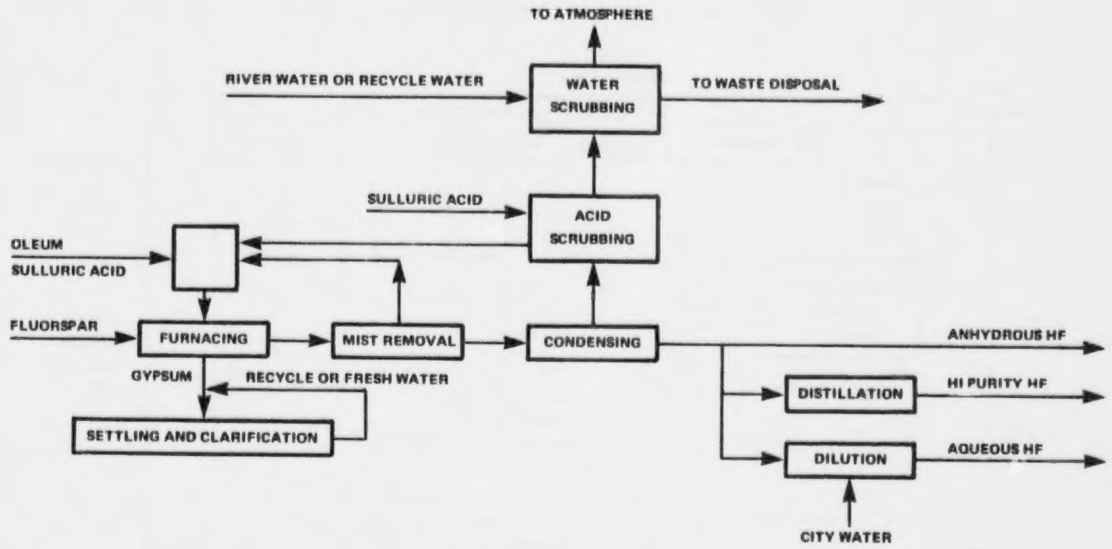


FIGURE 2 SETTLING POND RECYCLE/REUSE SYSTEM

ALLIED CHEMICAL COMPANY
NITRO, WEST VIRGINIA

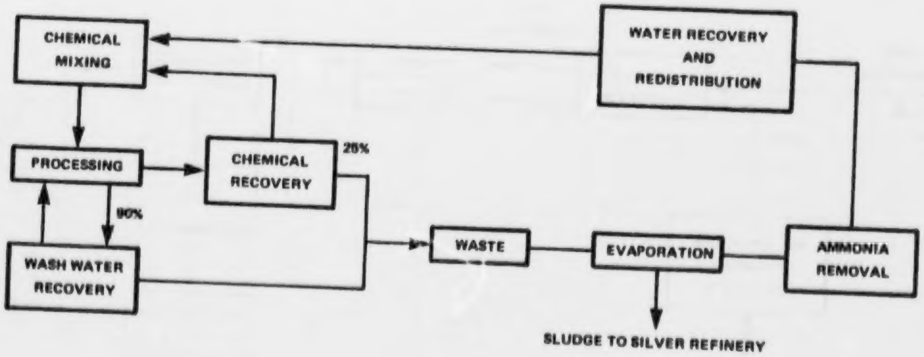


FIGURE 3 ZERO DISCHARGE SYSTEM

PCA INTERNATIONAL, INC.
MATTHEWS, NORTH CAROLINA

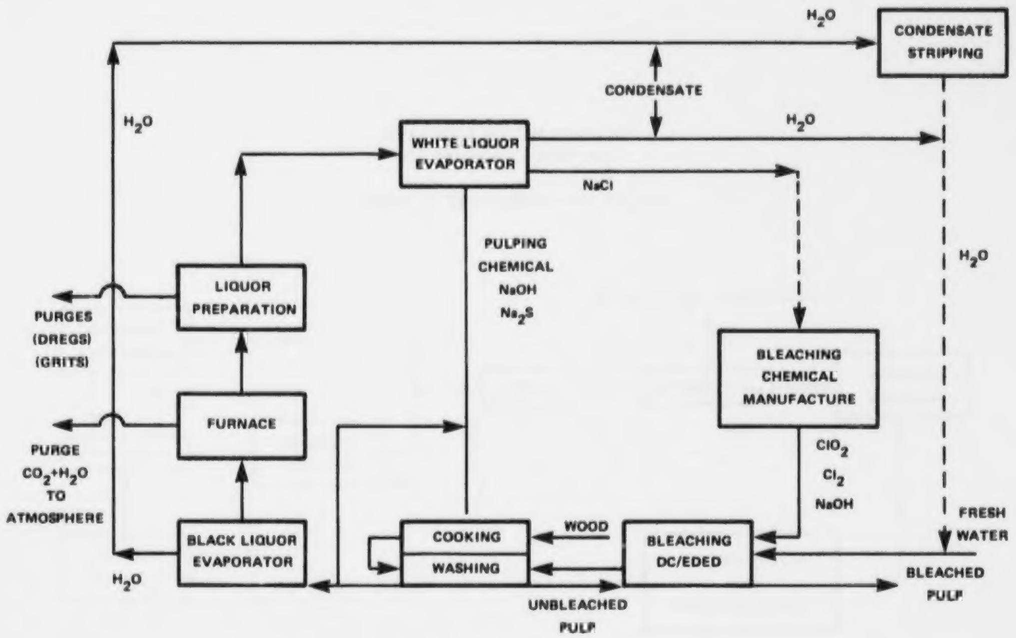


FIGURE 1 CLOSED-CYCLE BLEACHED KRAFT PULP MILL SYSTEM

GREAT NORTHERN PAPER COMPANY
THUNDER BAY, ONTARIO

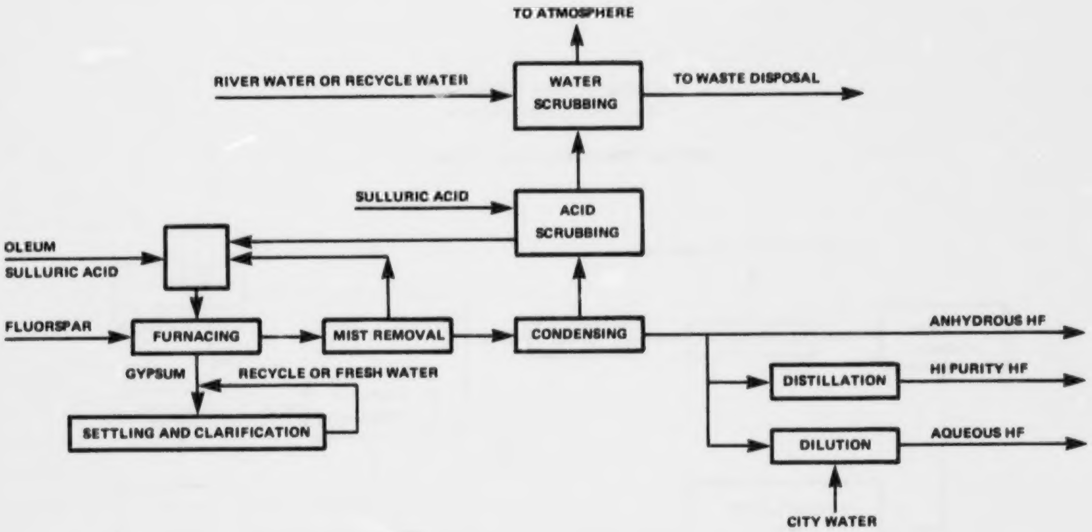


FIGURE 2 SETTLING POND RECYCLE/REUSE SYSTEM

ALLIED CHEMICAL COMPANY
NITRO, WEST VIRGINIA

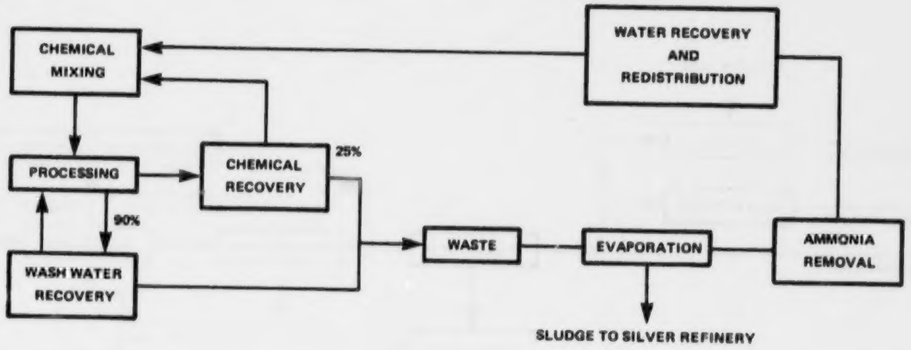
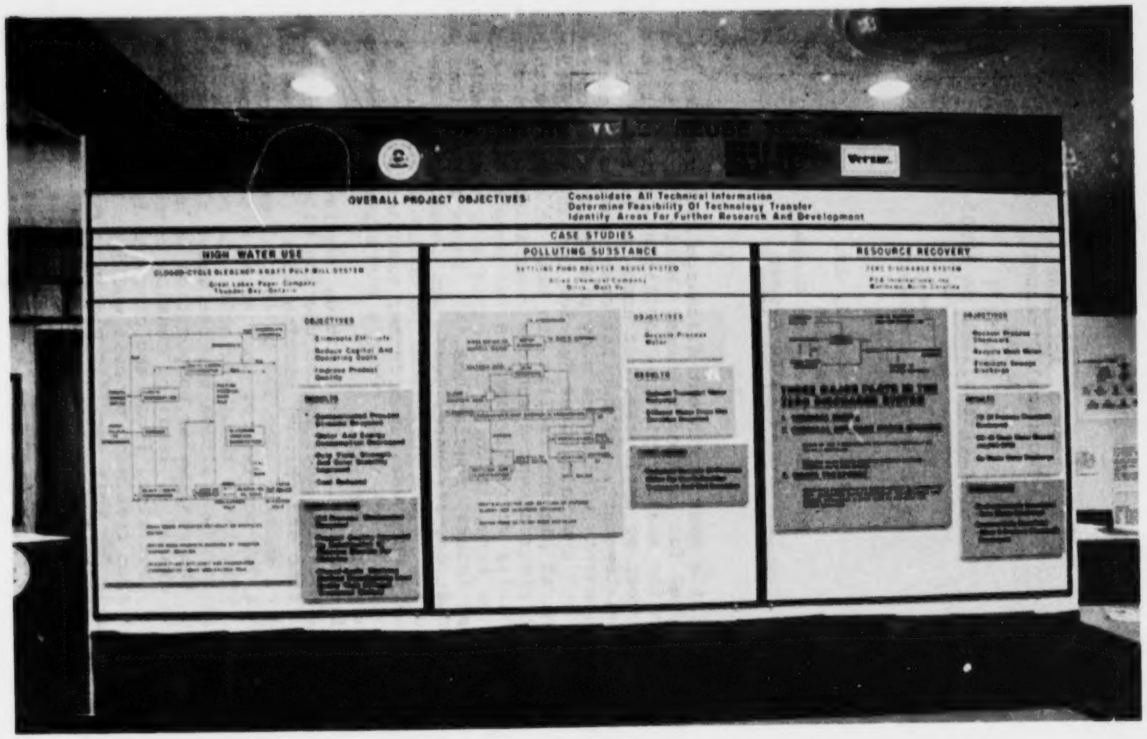


FIGURE 3 ZERO DISCHARGE SYSTEM

PCA INTERNATIONAL, INC.
MATTHEWS, NORTH CAROLINA


Versar
OVERALL PROJECT OBJECTIVES:
Consolidate All Technical Information
Determine Feasibility Of Technology Transfer
Identify Areas For Further Research And Development
CASE STUDIES
HIGH WATER USE
CLOSED-CYCLE BLEACHED KRAFT PULP MILL SYSTEM
Great Lakes Paper Company
Thunder Bay, Ontario
OBJECTIVES
Eliminate Effluents
Reduce Capital And Operating Costs
Improve Product Quality
RESULTS
POLLUTING SUBSTANCE
SETTLING POND RECYCLE/REUSE SYSTEM
OBJECTIVES
Recycle Process Water
RESULTS
RESOURCE RECOVERY
ZERO DISCHARGE SYSTEM
OBJECTIVES
Reduce Process Chemicals
Recycle Wash Water
Eliminate Sewage Discharge
RESULTS

RECYCLING SYSTEM FOR MECHANICAL PLATERS

Roy A. Ackerman
Technical Director
ASTRE
P.O. Box 5072
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Samuel C. Crosby
Principal Engineer
ASTRE

R.E Ellingwood, Jr.
President
Soft Water Service Company
E. 25 Third Avenue
Spokane, WA 98103

One of the most stringent discharge requirements is that developed for plating systems. While EPA has made a distinction for smaller plating facilities (currently based upon the number of employees, but soon to be based upon the volume of wastewater), the capital costs needed to meet these requirements will force many plants to cease operation.

ASTRE and the Soft Water Service Company were retained by a mechanical plating facility to help it comply with state and federal pretreatment discharge regulations. Since this plating facility currently employs ten people and has a small effluent flow rate, it would be fairly simple to comply with the proposed federal regulations.[1,2] These regulations deal only with cyanide, chromate, lead, and cadmium, but the state authority wanted additional pH controls and flow equalization.[3] However, upon futher examination, it was quickly realized that reuse/recycle might prove to be the most economic alternative.

The plating facility in question consists of a degreasing/descaling unit in conjunction with a proprietary mechanical (zinc and chrome) plating unit. The wastewater volume is very small-- some 300 to 400 gallons per cycle. A normal work day consists of some seven cycles. However, since each cycle takes about one hour, and not every phase of the cycle incurs a discharge, the water flow is sporadic. In addition, the wastewater composition is highly variable. There are no cyanides, lead, or cadmium concentrations in the effluent, but zinc, iron, and chromium levels are high. Any contemplated treatment process would obviously have to be tailor-made for this specific plating system. (Although there are scores of these units being used, there have been no specific treatment units employed to solve their discharge problems.) Therefore, the treatment unit was designed to be installed in stages to minimize the capital budget outlays for the system.

PHASE ONE

The first problems resolved included the segregation of the various wastewaters in the process, the installation of a pH control system, a chrome reduction unit, and effluent flow equalization. The next phase included the introduction of sedimentation and filtration operations, as well as chrome recovery, with subsequent water recycle. The devices used in the first stage were chosen to insure their continued applicability in the recycle/recovery phase, thereby reducing the costs of having, in essence, two systems (the first and second phases of the design).

The pH of the wastewater before treatment is typically in the range of 2 to 4. The controller was set to maintain the pH within a range of 7 to 8, using caustic soda as the neutralizing agent. Caustic soda was chosen (instead of lime, for example) since it is readily available in solution form and can be easily metered into the system. To insure close tolerance, the expanded scale was employed for all pH control operation (instead of using a more expensive two-stage pH control system).

Agitation in the pH control tank was effected using a draught tube aerator/mixer. The aeration rate was on the order of 0.11 ℓ/ℓ-min (0.15 cfm/gal). The average mixing time within the tank is five seconds, as determined by dye tracer tests. Initially, the pH control tank was 227 ℓ (60 gal). This sizing was based upon the anticipated 0.5 ℓ/s (8 gpm) flow rate from the zinc plating process. However, that flowrate required a larger equalization tank (see figure 1) than space allowed. The transfer pump was, therefore, changed to provide a 2 ℓ/s (31 gpm) flow rate to the control tank.

This change necessitated that a 630 ℓ (167 gal) tank be used for the pH control step (mixing time remained nearly five seconds). The retention time thereby became 5.25 min, which was 30% shorter than the design dictated. This modification has caused the controller to undershoot/overshoot the desired pH range. A further adjustment, increasing the caustic pumping capacity from 36.4 cm^3/s (0.57 gpm) to 63.3 cm^3/s (1 gpm), has rectified the problem.

From the pH control unit, the wastewater overflows to a flow equalization basin. The flow was equalized using an unusual approach (and not requiring any extra pumps). A restriction orifice 5 cm from the tank bottom allowed effluent to enter the municipal sewer, but only at a very low flow rate (which was dependent upon the height of the liquid in the tank). As the level in the tank rose, it activated a siphon, having a larger orifice than the lower drain, and provided a more rapid flow rate. This concept has proved exceptionally efficient, giving a continuous (during plant operation) average flow rate on the order of 0.3 ℓ/s (5 gpm), instead of the 2 ℓ/s (31 gpm) influent to the system over a much shorter time frame.

Hexavalent chrome was reduced on a batch basis. The chrome waste (at a pH of 2) from each cycle enters a holding tank, which is level controlled. From there, the wastewater is pumped (0.5 ℓ/s) to a separate tank, the chrome reduction tank. Gentle agitation is provided by diffused air at a rate of 0.06 ℓ/ℓ-min (0.08 cfm/gal) throughout the working day. Originally, it was hoped that the plating mechanic would determine the level of sodium metabisulfite needed to reduce the chrome (using wet chemical analysis) and add it to the tank at the end of the day. This concept proved troublesome. First of all, the operator did not choose to add the metabisulfite to the wastewater at all, since the resultant odors were highly objectionable. Secondly, errors in the analysis were routinely effected so the hexavalent chrome was only partially treated. Therefore, an oxidation-reduction potential (ORP) electrode was purchased.

The procedure was then changed so that at the end of the day, the pH electrode was disconnected from the control unit, the caustic pump was disconnected also, and the ORP electrode and the metabisulfite solution pump were connected in their stead. Overnight, the ORP of the chromium wastewater is adjusted, effecting the chromium reduction. Then, the next morning, the pH electrode and caustic pump are reconnected (and the ORP system disconnected), and the treated wastewater is pumped (0.5 ℓ/s) to the pH control tank and on through the system. The total cost for the first phase, including all expenses, labor, and materials, as well as modifications to the plating unit to improve its performance, did not exceed $8000.

SECOND PHASE

The second stage system used the same tanks as previously described. Now, however, the chrome-bearing wastewater is to be fed to a two-bed ion exchange system. The effluent from the exchangers can be used as final wash water.

The beds are comprised of a macroporous weak base anion exchanger (50 cm of resin) and a macroporous strong acid cation exchanger (50 cm of resin). The system is operated in the downflow mode, at a flow rate of 4 cm/min (1.2 gpm/sq ft). The retention time in each bed is 10 min.

The ion exchangers perform well, in spite of the oxidant dosage, because of the resin choice made and because the chromium levels are low, even during the regeneration phase (never exceeding 4% chromic acid, which is the required strength for the plating operation).

The exchangers are to be regenerated about once a month, when they have been about 25% expended. This bed regeneration is carried out in two steps. (Both steps are in the upflow configuration, to insure that the portion of the bed which is not regenerated and allows leakage is subjected to ion exchange prior to fluid emergence from the bed.) First, the cation bed is regenerated using 4% sulfuric acid (2 cm/min). Then, the anionic bed is regenerated with 4% caustic soda, and the regenerating solution is passed (2 cm/min) through the previously regenerated cationic bed, where the sodium ion (from the sodium chromate) displaces the hydrogen ion on the bed, and chromic acid is formed. Regenerating the resin beds, therefore, allows for the recovery of chromic acid, thereby reducing the need to purchase some of the chrome plating chemicals.

The pH controller will now be set at pH 8.5 to 9.5. At this pH level, heavy metals, such as zinc and iron, easily settle out. The treated zinc and iron waste will flow to the sedimentation tank (which is the old flow equalization basin). The bottom port (which was used to maintain a slow, steady flow), is now used solely for sludge removal. Settled water now flows through the top port (which was the siphon port), to a cartridge filter, where residual floc particles are removed. From the cartrdige filter, the water is sent to and held in the original chrome waste holding and reduction tank, now used for holding treated water. This water is then used for washing plated parts (but not the final rinse), make-up for the degreaser, and to feed the eductor pump, which is an integral part of the mechanical plating unit.

The capital costs for this phase of the design and installation are $6500, and the total operating costs average $10 to $15 per week. The implementation of this phase has been delayed because of the planned introduction of a galvanizing line to the facility. This new operation would radically change the needs for the wastewater treatment systems, so further upgrading of the present system has been temporarily halted. However, if, as expected, the galvanizing facility will be located elsewhere, then the second phase will be immediately instituted. It is expected that the process water will be reused some 40 times prior to discharge (as demonstrated by the pilot tests), reducing the water demand from 2400 gpd to 300 gal/wk, when the second phase is totally operational.

With a total installation cost of less than $ 15,000 and maximum annual operating costs of $ 750 (with no credit given for chrome recovery by the system), treating and recycling plating wastewater may not have to be an undue burden for smaller plating facilities. This is especially true if the system is installed in phases, to minimize the initial capital outlays and to train the operating personnel properly.

REFERENCES

1. Code of Federal Regulations. Title 40, 193-206 (1977).
2. Federal Register. 43,31:6560-6573 (1978).
3. Rhys A. Sterling, private communication.

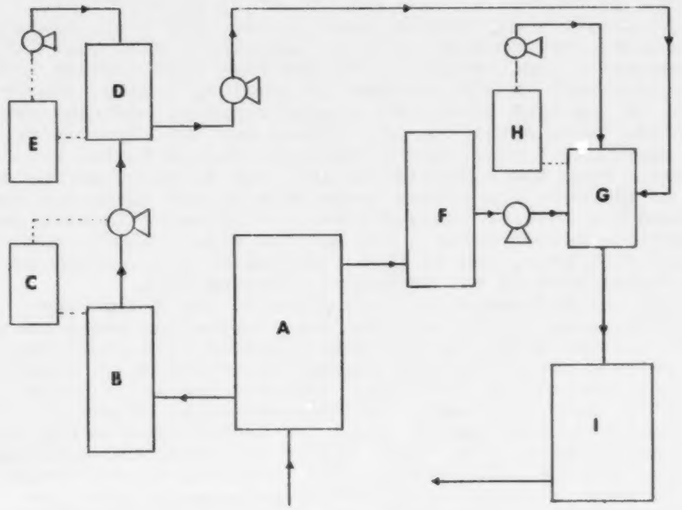


FIGURE 1. SYSTEM SCHEMATIC

Key To Figure 1:

A- plating facility
B- chrome waste equalization basin
C- level control for holding tank
D- chrome reduction tank
E- ORP controller (same physical piece as H)
F- Zinc Wastewater Equalization Basin
G- pH Contrcl tank
H- pH controller (same physical item as E)
I- Flow Equalization basin

"AMARILLO'S WATER SUPPLY = 70% NEW + 30% REUSED"

Clarence H. Scherer
Water Reclamation Superintendent

This is a poster project showing the overall water picture for the City of Amarillo and the part that the re-use of wastewater effluent plays in it. The City of Amarillo has been successfully reclaiming wastewater and selling it ot industrial customers for nonpotable use since 1954. A major power company is currently purchasing almost all of the effluent produced at the city's 12 MGD River Road Plant and will in the near future be using most of the effluent from the newly expanded 8 MGD Hollywood Road Plant when that project is completed. At that time, some 30% of the City of Amarillo's total water supply will be made up of reclaimed wastewater effluent, or "re-used water". The balance of the city's water needs are taken from diminishing underground water sources and from a surface lake.

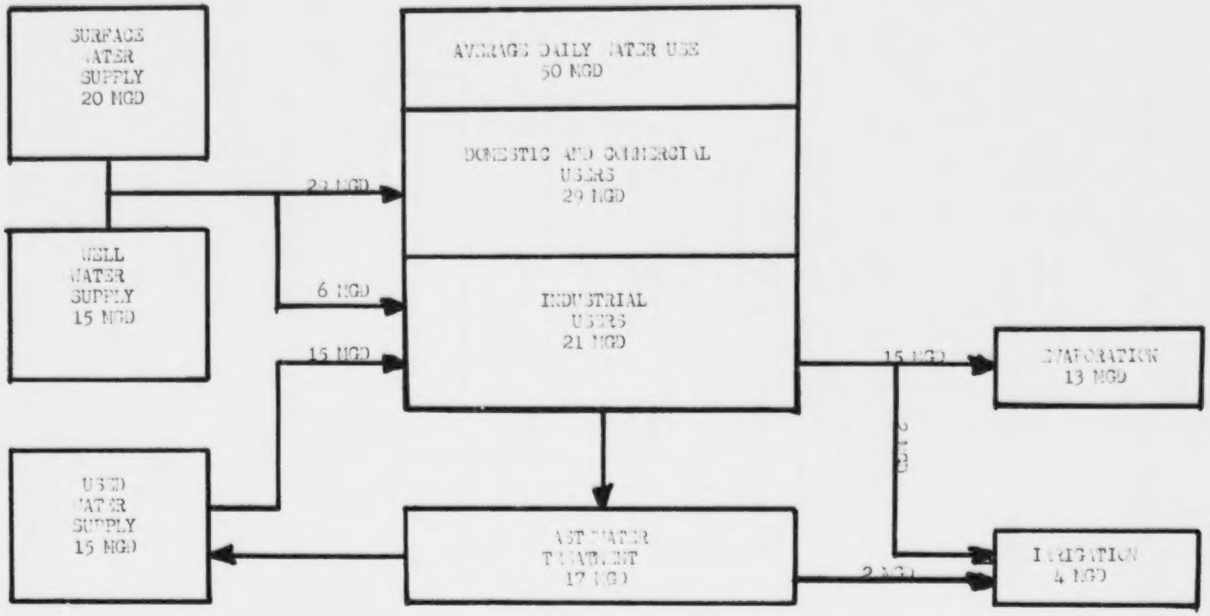
AVERAGE DAILY WATER USE

50 MGD

Amarillo, Texas, with a population of about 160,000, is located on the upper High Plains of West Texas. The entire area is considered semi-arid with an annual rainfall of 18 to 20 inches.

The economy is generally based on cattle, agriculture, and petroleum. Due to its location, the City of Amarillo serves as a major transportation and supply center.

More than 200 manufacturing plants are situated in Amarillo. The diversified industrial units include a copper refinery, helicopter maintenance and overhaul facilities, meat packing plants and fiberglass manufacturing, plus clothing, wood products, farm equipment, cement, helium, and other goods.



AMARILLO'S WATER SUPPLY = 70% NEW + 30% REUSED

Of the 50 MGD average daily water use by the City of Amarillo, some 29 MGD is provided to domestic and commercial users as a constant blend of 70% surface water and 30% well water. Major industrial users consume an additional 21 MGD which is made up of 15 MGD of reclaimed wastewater for non-potable purposes and 6 MGD of either surface or well water provided directly to certain industrial customers for specific needs.

SURFACE
WATER
SUPPLY
20 MGD

The City of Amarillo is a member of the Canadian River Municipal Water Authority. This organization was founded in 1965 by 11 cities on the High Plains of West Texas. It's purpose was to build a dam across the Canadian River some 30 miles northeast of Amarillo, and build and operate the necessary pump stations and pipe lines to deliver municipal water to the member cities.

The City of Amarillo's share of the yield from this source--Lake Meridith--is a maximum of 34 MGD. At the present time, the city is using some 20 MGD of this surface water.

Amarillo has a conventional surface water treatment plant to provide chemical clarification, sand filtration, taste and odor control, and disinfection for this surface supply.

WELL
WATER
SUPPLY
15 MGD

The City of Amarillo currently has 103 water wells in the Ogallala formation. This water, while of excellent chemical quality, is present in limited quantities. There is essentially no recharge to the Ogallala formation, therefore, water that is removed is essentially "mined".

Of the 103 existing wells, only 33 are in high yielding areas. The other 70 are in shallow formations and are from 30 to 50 years old.

The city owns water rights in the existing Carson County Field (33 wells) for development of an additional 36 units expected to yield an average of 1,000 gallons per minute each.

In addition, the City of Amarillo owns 100,000 acres of water rights in a shallower area of the Ogallala formation, some 50 miles to the northwest. This more expensive water will probably be developed in the mid to late 1990's.

USED

WATER

SUPPLY

15 MGD

As early as 1954 the City of Amarillo developed an active project in cooperation with a local refinery to provide non-potable industrial water from the City's activated sludge wastewater treatment plant. This project was so successful that an area power company became interested and started purchasing reclaimed water for cooling at a new generating station in 1960. They are now using some 12 million gallons per day of reclaimed water in 5 power generating units producing more than a million kilowatts of electricity. On completion of their third new coal-fired plant next year, the power company's total reclaimed wastewater use will be more than 14 MGD. The original refinery customer is still using this water for cooling and boiler make up.

Both industrial customers find it necessary to treat this reclaimed water for reduction of phosphates to prevent scaling, but generally no other secondary treatment is needed.

Reclaimed wastewater sold to these industrial customers is used strictly for non-potable uses described above, but replaces an equal amount of fresh water that would otherwise be needed by these customers.

WASTEWATER
TREATMENT
17 MGD

Wastewater treatment for the City of Amarillo is provided in 2 activated sludge plants located some distance to the north and south of the city. These plants provide secondary treatment for approximately 70% of the domestic and industrial wastewater generated in the city. The balance of the wastewater is treated in separate treatment systems privately owned and operated by industry. Much of this privately treated industrial wastewater is highly mineralized "blow down" from the power generating plants which is disposed of by evaporation and irrigation.

The city's activated sludge wastewater treatment plants consistantly produce effluent with less than 20 milligrams per liter B.O.D. and suspended solids.

Strict enforcement of industrial waste controls, coupled with highly trained and competent operating and maintenance personnel and solid support from management contribute to this constant high quality reclaimed water and to the success of this entire water reuse program.

EVAPORATION
13 MGD

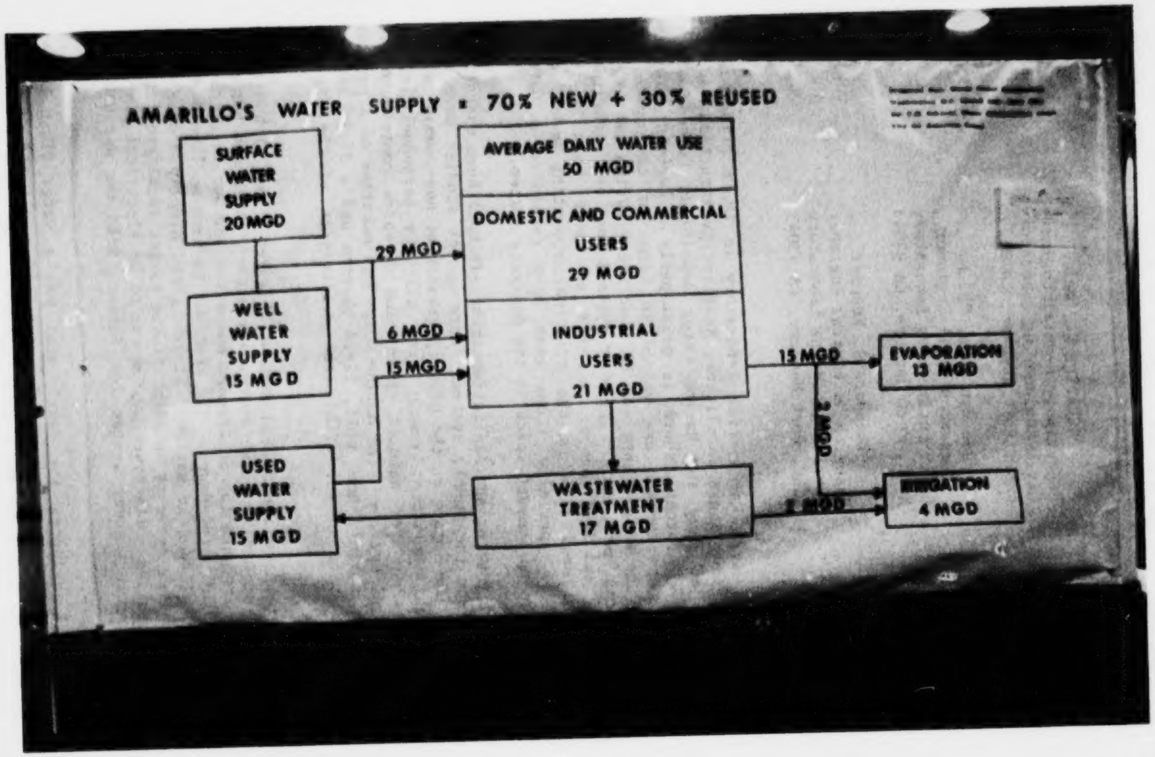
In the semi-arid climate of West Texas with an evaporation rate of some 6 feet per year, a lot of water goes up into the air. The city's power company reclaimed water customer loses some 11 million gallons a day of water to evaporation in the cooling towers and in blow down lakes. The city's refinery reclaimed water customer evaporates some 1 million gallons a day in their cooling towers and blow down ponds. In addition the city loses approximately 1 million gallons a day of effluent from their Hollywood Road Wastewater Treatment Plant 500 acre shallow lake to evaporation.

IRRIGATION

4 MGD

At the present time the power company reclaimed water customer is using some of their cooling tower blow down for irrigation of salt tolerant crops. This water normally contains some 6,000 milligrams per liter of total dissolved solids, and considerable attention must be paid to application rates, soil preparation, type of crops raised and other factors.

Also at the present time the city is selling some 2 MGD of treated effluent from the Hollywood Road Wastewater Treatment Plant to farmers in the immediate area. These customers are irrigating feed crops such as wheat, maize, and corn.


AMARILLO'S WATER SUPPLY = 70% NEW + 30% REUSED
SURFACE WATER SUPPLY 20 MGD
WELL WATER SUPPLY 15 MGD
USED WATER SUPPLY 15 MGD
29 MGD
6 MGD
15 MGD
AVERAGE DAILY WATER USE 50 MGD
DOMESTIC AND COMMERCIAL USERS 29 MGD
INDUSTRIAL USERS 21 MGD
WASTEWATER TREATMENT 17 MGD
15 MGD
2 MGD
2 MGD
EVAPORATION 13 MGD
IRRIGATION 4 MGD

MILITARY FIELD SANITATION AND WASTEWATER REUSE

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The Navy's Civil Engineering Laboratory is their principal R&D center for Navy Shore Facilities, Seafloor Construction, and for projection of Navy and Marine Corps Amphibious Forces ashore. Projection of forces ashore is principally a logistic problem. Materials and supplies are valued in terms of the space they occupy and the weight they add to a delivery system (ships, aircraft, trucks, men, etc). Logistic systems must be constrained to handle the smallest number possible of large quantity items. Large scale mass flow is the principal operating mode. Small quantities of specialty items must have considerable tactical significance to command space in the delivery system.

Traditionally water and sanitation chemicals have been essentially excluded from the supply system. More recent studies have begun to measure the impact on the primary mission of non-combat casualties. Such casualties result from military personnel leaving sheltered areas for natural relief and diseases contributed to poor physical hygiene. The Marine Corps has embarked on a program to develop a field head unit, field showers and a field laundry system that are useful within the constraints of the logistic systems.

The expeditionary field head module (Figures 1 and 2) had to be odor free for use in close spaces (transport ships and bunkers). It must be designed for unattended operation for not less than six months without maintenance. The unit was to have no liquid effluent or wet sludges to manage. It could not display a detectable smoke signal or serve as an identifiable target signature for heat seeking missiles. Its power system was to be electrical since the ultimate primary power system for future field use was undetermined.

The concept selected for development was a water flush toilet system that makes its own flush water from the urine deposits. The wet wastes are incinerated at 1,500°F. The stack gasses are cooled by dilution to below the ambient levels for the environment before they are released into the atmosphere.

A major problem in this development was the recovery of water from the urine to a quality satisfactory for flush water application.

Make-up water for flushing the toilet was discounted on the basis of logistic problems that could occur and the large energy supply and the larger physical capacity of the reactor that would be required for its evaporation.

The urine purification processes that have been investigated to date include ozonation, combination of ozonation and ultraviolet (UV) radiation, UV radiation, activated carbon adsorption, electrolysis and a physical/chemical process.

The criteria used in the investigation for measuring process effectiveness consisted of odor, color, turbidity, COD, TKN and total coliform.

The only flush water quality criteria that could be found published was taken from a U.S. Department of Interior report for domestic toilet flushing. These criteria were odor (3 units), color (30 units), turbidity (30 JTU) and total coliform (10,000 per 100 ml). Initially COD and TKN were added to the testing program. Finally in the electrolysis testing chlorides, TDS, free chlorine, TOC and pH were added.

EXPERIMENTAL PROCEDURES AND METHODOLOGIES

Pooled urine samples were collected for the study. Experimental procedures and methodologies used are described in the following.

1. Ozonation - One liter of diluted urine (with demineralized water, 1:1 by volume) prepared from pooled urine samples was placed under ozonation for 30, 90, 180 and 300 minutes contact time, respectively. To prepare the second and third batch a 1:1 (by volume) solution was prepared with the treated diluted urine. The objective was to investigate any build up of impurities. Table 1 shows the experimental set-up and operational characteristics of the ozonation system.

TABLE 1

Ozonation System Experimental Set-Up and Operational Characteristics

Ozone Generator	
Type	Grace Ozone Generator (from Union Carbine), Model LG-2-L1
Size, HxLxW	8 in. x 20 in. x 17.5 in.
Weight	115 lb
Power requirements	125 watts at 120 volts, 60 Hz
Power consumption (90 min)	0.20 kWhr
Ozone production	From Oxygen: 250 grams/day at 2% concentration by weight

continued

TABLE 1 CONTINUED

Gas Supply	
Type	Oxygen
Flow	0.20 liters per minute, l/min
Pressure	10 pounds per square inch gauge, psig
Contactor	
Type	Aquafine Electronic Liquid Sterilizer, Model SL-1*
Size, DxH	3-1/4 in. x 29-1/2 in.
Diffusers	
number	Two
pore size	50 microns
surface area	0.442 square inch
Ozone Decomposition Device	Potassium Iodide Solution
Ozone Dose Applied	81 milligrams per liter

*Modified by the author.

Samples were taken at the end of each designated contact time and analyzed for their physical, chemical and biological parameters, previously described.

2. Ozonation-Ultraviolet (UV) Radiation - This experiment was conducted with the same set up and in the same manner as the ozonation described above, except that the UV lamp (Westinghouse Sterilamp 637T6VH) was turned on during the specified ozone contact times. Table 2 lists the experimental set-up and operational characteristics of the Ozone-UV system.

TABLE 2

Ozonation-Ultraviolet Radiation System Experimental Set-Up and Operational Characteristics

Ozone Generator	
Type	Grace Ozone Generator (from Union Carbide), Model LG-2-L1
Size, HxLxW	8 in. x 20 in. x 17.5 in.
Weight	115 lb
Power requirements	125 watts at 120 volts, 60 Hz
Ozone production	From Oxygen: 250 grams/day at 2% concentration by weight

continued

TABLE 2 CONTINUED

Gas Supply	
Type	Oxygen
Flow	0.20 l/min
Pressure	10 psig
Contactor	
Type	Aquafine Electronic Liquid Sterilizer, Model SL-1*
Lamp	Westinghouse Sterilamp 637T6VH, 2537 Angstrom (A) range,
power requirements	0.5 Amps, 118 Volts, 60 Hz
Diffusers	
number	Two
pore size	50 microns
surface area	0.442 square inch (sq in.)
Ozone Decomposition Device	Potassium Iodide Solution
Ozone Dose Applied	81 milligrams per liter
UV Intensity	85 percent
Power consumption (90 min)	0.30 kWhr

*Modified by the author.

3. Activated Carbon Adsorption - Activated carbon adsorption isotherms were obtained using 800 milliliters (ml) of diluted urine (1:1 by volume). The activated carbons tested were (a) NUCHAR WV-L, (b) NUCHAR WV-G, (c) DARCO HD-3000, and (d) FILTRASORB 300. These isotherm experiments provided information on how effectively a specific carbon adsorbed the impurities contained in the diluted urine. The objective was to estimate the potential value of conducting time-consuming carbon column studies. Six beakers were filled with 800 ml of diluted urine. Five contained different amounts of carbon (325 mesh). The sixth beaker was the standard (without carbon). The carbon-urine solutions were agitated simultaneously for 10, 20, 30 and 60 minutes. At the end of the above contact time a sample was taken from each beaker, filtered (to remove trace carbon) and analyzed for the parameters described previously. The adsorption isotherms were obtained at room temperature.

The adsorption isotherm shows the distribution of organic contaminants (adsorbate) between the adsorbed and the solution phases. A plot of the amount of impurity adsorbed against the amount of impurity remaining in solution was prepared. In this case (liquid phase) empirical line plots were made using the empirical Freundlich equation. This equation relates the amount of impurity in the solution phase to that in the adsorbed phase by the expression:

$$X/M = kc^{1/n}$$

where X = amount of contaminant adsorbed

M = weight of carbon

X/M = concentration in the adsorbed state (i.e., the amount of contaminant adsorbed per unit weight of carbon)

c = remaining contaminant concentration in solution

k,n = constants

In logarithmic form:

$$\log X/M = \log k + 1/n \log c$$

where 1/n represents the slope of the straight line isotherm.

An adsorption isotherm was not performed using FILTRASORB 400. Satisfactory results were found reported in the literature by Sulick. The types of carbons selected for column study were NUCHAR WV-L and FILTRASORB 400.

a. Carbon Columns

(1) NUCHAR WV-L

The carbon column study consisted of two plexiglass columns connected in series. Table 3 lists the construction and operational characteristics of the activated carbon adsorption system using NUCHAR WV-L.

Pooled urine samples were collected in 1 liter wide-mouth plastic bottles and stored in an 8°C refrigerator. Twelve (12) liters of raw urine were collected and diluted with demineralized water (1:1 dilution by volume).

The carbon was placed in deionized water and left overnight to ensure that all the gases entrapped in the carbon pores were removed. Each column was half filled with deionized water. The carbon was carefully poured into the column, keeping the liquid level above the surface of the carbon. The carbon was then backwashed with deionized water to remove entrained air and fines. The carbon was then allowed to settle and the water was drained to a level about 1 inch above the carbon bed. The depth of the bed was measured and its volume calculated. Retention time for the diluted urine to be treated was calculated.

$$\text{Retention Time} = \frac{0.4 \times \text{Carbon Bed Volume}}{\text{Flow Rate}}$$

where 0.4 is the void fraction in the carbon bed.

TABLE 3

Carbon Adsorption Column System Using NUCHAR WV-L Construction and Operational Characteristics

Carbon Column	
Number	Two, 43.7 grams per bed
Diameter, ID	5/8 in.
Depth	21 in.
Arrangement	In series
Material	Plexiglass
Tubing	
Size	1/4 in.
Type	Tygon
Liquid Storage	
Type	For influent - plastic For treated - glass
Operating Characteristics	
Flow Rate/Unit Area, Q/A	0.5 gallons/square foot (gpm/sq ft) or 4 ml/min
Flow Rate/Unit Area, Q/A	1.0 gpm/sq ft or 8 ml/min
Flow regime	Up flow
Type of operation	Continuous
Retention Time	~11 min/bed at Q/A = 0.5 ~5.5 min/bed at Q/A = 1.0
Pumps	
Type	Cole Parmer Peristaltic 22
Number	Three (two for waste, one for backwashing)
Energy requirements	0.5 Amps, 115 Volts, 60 Hz
Energy Consumption	
During Q/A = 0.5 gpm/sq ft	1.32 kWhr
During Q/A = 1.0 gpm/sq ft	0.63 kWhr

The diluted urine was placed in the influent storage containers and pumped at the given flow rate (see Table 3). Samples were collected at specified time intervals and analyzed for the parameters listed. This process was continued until the impurity concentration in the effluent from the second column became greater than the assigned standard. When the effluent flow began to decrease below the influent reading the columns were backwashed with distilled water for 15 minutes.

Two different flow rates were evaluated to measure the effect of flow rate change on the adsorption rate. It had been reported that increasing the flow rate reduces the volume of acceptable effluent produced at a given bed depth. Records were kept on the total volume of diluted urine processed.

(2) FILTRASORB 400

During the adsorption studies with FILTRASORB 400, the same column system as used with NUCHAR WV-L was utilized. Table 4 illustrates the experimental set-up and operational characteristics of the carbon adsorption system. The operational procedures were the same as NUCHAR WV-L except the flow rate of 4 ml/min was changed to 14 ml/min.

TABLE 4

Carbon Adsorption Column System Using FILTRASORB 400
Construction and Operational Characteristics

Carbon Column	
Number	Two, 42.2 grams per bed
Diameter, ID	5/8 in.
Depth	21 in.
Arrangement	In series
Material	Plexiglass
Tubing	
Size	1/4 in.
Type	Tygon
Liquid Storage	
Type	For influent - plastic For treated - glass
Operating Characteristics	
Flow Rate/Unit Area, Q/A	1.0 gpm/sq ft or 8 ml/min
Flow Rate/Unit Area, Q/A	1.75 gpm/sq ft or 14 ml/min
Flow regime	Up flow
Type of operation	Continuous
Retention time	~5 minutes/bed at Q/A = 1 ~3 minutes/bed at Q/A = 1.75
Pumps	
Type	Cole Parmer Peristaltic
Number	Three (two for waste, one for backwashing)
Energy Requirements	0.5 Amps, 115 Volts, 60 Hz
Energy Consumption	
During Q/A = 1.0 gpm/sq ft	0.63 kWhr
During Q/A = 1.75 gpm/sq ft	0.80 kWhr

4. Ultraviolet Radiation - One liter of diluted urine was placed in an Aquafine Electronic Liquid Sterilizer (Model SL-1), see Table 1. The diluted urine was exposed to UV radiation for 30, 90, 180 and 300 minutes, respectively. Samples were taken at the end of each contact time and analyzed for the water quality parameters. The percent of UV intensity applied was 85. The intensity of radiation generally means the rate of supply of radiation energy to a unit area of flat surface (e.g., a square centimeter perpendicular to the direction of radiation). Although UV is primarily used as a disinfecting agent, the authors were interested in the potential for photochemical reactions induced by UV radiation that could reduce dissolved organics. Some photochemical reactions did occur as measured by reduction in dissolved organics.

Experimental procedures and methodologies are summarized as follows.

Methods	Parameters	Analytical Techniques
Ozonation[1]	Odor[2]	Dilution
	Color[3]	Colorimetric
	Temperature	Conventional Thermometer
	Turbidity[3]	Turbidimeter
	COD[4]	Potassium Dichromate
	TKN[2]	Digestion
	Total Coliform[2]	Millipore Filtration
Ozonation-UV[1]	Same as above	Same as above
Ultraviolet	Same as above	Same as above
Carbon Adsorption	Odor	Dilution
	Color	Colorimetric
	Temperature	Conventional Thermometer
	Turbidity	Turbidimeter
	COD	Potassium Dichromate
	TKN	Digestion

[1] Ozone was analyzed by the Potassium Iodide technique.

[2] Used Standard Methods for the Examination of Water and Wastewater, 13th Ed.

[3] Used HACH procedures and HACH DR-IR Colorimeter.

[4] Samples were digested for 3 hours.

5. Electrolysis - An electrolysis test cell developed during the NASA Program as a stage in the recycling of urine for potable water was used to test the feasibility of producing flush quality liquid in essentially one stage via electrochemical reaction.

The objective of this test phase was to show the feasibility of using a particular electrolysis design to treat undiluted urine in order to produce flush quality liquid. During all tests a flow rate of 1 liter per minute of undiluted urine was maintained. Power inputs and processing times were varied to attain an overall measure for the various operational parameters involved. Liquid quality samples were taken at the end of each process run when the observed color was within evaluation criteria standards. Interim samples were taken during two test runs to observe the liquid quality progression that occurs while the electrolysis process was underway. The following table shows the two sets of tests conducted.

TABLE 5

Experimental Procedures for Electrolysis

Test Run	Operational Parameters	Liquid Quality Parameters Analyzed
1-4	Constant Power Input	Color; chloride; TDS; COD; free chlorine; TKN; TOC; pH
5-9	Varied Power Input	Same as above

6. Physical/Chemical Process - A water recycling system being tested in the prototype field head unit involves the simultaneous application of the following processes in a single tank:

(1) Gas stripping
(2) Pasteurization
(3) Oxidizing chemical addition
(4) Coloring agent addition

Pasteurization temperature is maintained continuously for disinfection purposes while gas stripping removes volatile ammonia gas. An oxidizing chemical addition provides partial color removal and a residual disinfectant capability. A coloring agent provides aesthetically pleasing flush color. This system has operated satisfactorily within the range of limited field testing conducted thus far. Although this system began as a field expedient method for flush liquid treatment, testing has shown these processes to have a synergistic effect upon one another which provides treatment better than one would normally expect. One major drawback, however, is that a chemical and a coloring agent must be added to complete treatment. This logistic requirement for the sanitation facility is undesirable and is a primary reason for seeking alternative urine treatment methods. Liquid quality testing is continuing and further options will be reported upon later this year.

EXPERIMENTAL RESULTS

The results presented herein include those resulting from all the unit treatment processes studied.

1. Ozonation - Three different experiments were conducted to investigate the removal rates of COD, Color, Odor, Turbidity and TKN. Effects of pH and temperature were evaluated. The procedure for conducting these experiments has been described in previous sections. The Tables below show the percent remaining and initial concentration of impurities for each run after each contact time and before ozonation, respectively. TKN was analyzed only after 300 min of contact time.

Disinfection of diluted urine was conducted separately but under the same operational conditions as the other Ozonation experiments. The Table below gives the percent of *E. coli* remaining after being subjected to Ozonation.

Percent Impurities Remaining After Ozonation

Run	Cum. Contact Time, min	Percent Remaining				
		COD	Color	Odor	Turbidity	TKN
1	30	65	90	80	102	
	90	58	20	70	12	
	180	53	5	60	0	
	300	48	11	60	6	94
2	30	93	82	80	100	
	90	84	31	64	33	
	180	79	15	64	11	
	300	68	3	55	0	100
3	30	84	58	73	46	
	90	81	25	64	25	
	180	78	12	55	11	
	300	67	7	45	14	100

Initial Impurities Concentration Before Ozonation

Run	COD mg/l	Color Units	Odor OII	Turbidity JTU	TKN mg/l
1	5,808	455	10	83	3,920
2	3,816	390	11	75	3,400
3	5,724	430	11	104	5,400

Contact Time, min	Control*	Sample**
5	98	73
15	82	1
20	91	0
30	72	0

*Initial E. coli concentration 1.14×10^{8}

**Initial E. coli concentration 1.14×10^{8}

2. Ozonation-Ultraviolet Radiation - Three different experiments were conducted to investigate the efficiency of impurities removal using the combination of Ozonation and Ultraviolet Radiation. The procedure for conducting these experiments is described in the previous section.

The Tables below show the percent remaining and initial concentration of impurities for each run after each contact time and before ozonation-UV, respectively. TKN was analyzed only after 300 minutes of contact time.

Percent Impurities Remaining After Ozonation-Ultraviolet Radiation

Run	Cum. Contact Time, min	Percent Remaining				
		COD	Color	Odor	Turbidity	TKN
1	30	65	97	73	100	
	90	62	13	64	0	
	180	58	10	64	0	
	300	46	8	45	14	97
2	30	84	71	82	77	
	90	72	0	64	77	
	180	67	0	55	0	
	300	49	12	55	13	98
3	30	71	76	82	56	
	90	61	46	64	56	
	180	52	30	55	7	
	300	40	6	45	0	99

Initial Impurities Concentration Before Ozonation-UV

Run	COD mg/l	Color Units	Odor OII	Turbidity JTU	TKN mg/l
1	5,034	380	11	70	3,488
2	5,221	340	11	62	3,672
3	4,819	330	11	70	5,600

Disinfection of diluted urine was conducted separately but under the same operational conditions as the other Ozonation-UV Radiation experiments. The Table below gives the percent of E. coli remaining after being subjected to Ozonation-UV Radiation.

Percent E. coli Remaining After Ozonation-Ultraviolet Radiation

Contact Time, min	Control*	Sample**
5	92	55
15	66	0
20	60	0
30	59	0

*Initial E. coli concentration 11.3×10^7

**Initial E. coli concentration 11.3×10^7

3. Carbon Adsorption - Four different types of carbon were tested by conducting adsorption isotherms. NUCHAR WV-L isotherm characteristics were far superior to the other carbons tested, and for this reason was selected along with FILTRASORB 400 for column experiments. Breakthrough curves (for each required parameter) for NUCHAR WV-L and FILTRASORB 400 were attained and plotted. The percent impurities remaining, calculated from the results obtained during carbon adsorption using NUCHAR WV-L at Q/A = 1.0 and 0.5 gpm, are summarized in Tables 6 and 7, respectively.

TABLE 6

Percent Impurities Remaining NUCHAR WV-L (Q/A = 1.0 gpm/sq ft)

Cum. Vol Liters	COD	Color	Odor	Turbidity	TKN
		Column 1*			
0.96	27	26	50	51	
1.93	44	29	40	50	
3.38	32	29	50	50	
4.34	48	33	60	67	
5.35	51	35	70	49	
6.75	65	51	80	96	
8.20	60	38	100	50	
9.65	61	46	100	64	
11.10	32	49	100	57	
12.54	69	55	100	60	
13.99	67	48	100	47	
15.92	54	53	100	53	
17.37	62	60	100	74	

continued

TABLE 6 CONTINUED

Cum. Vol Liters	COD	Color	Odor	Turbidity	TKN
			Column 2*		
0.92	18	24	30	48	
1.83	31	19	40	31	
3.20	26	11	30	14	72
4.12	37	20	60	45	
5.04	40	29	60	53	
6.45	45	37	80	68	
7.78	66	26	80	40	
9.16	42	31	90	68	81
10.53	43	35	90	57	
11.90	47	38	90	58	
13.28	55	30	90	37	
15.11	37	23	100	17	
16.48	47	30	100	40	

*Average initial impurities concentration
COD = 3,783 mg/l
Color = 342 units
Odor = 10 OII
Turbidity = 77 JTU
TKN = 2,900 mg/l

TABLE 7

Percent Impurities Remaining NUCHAR WV-L (Q/A = 0.5 gpm/sq ft)

Cum. Vol Liters	COD	Color	Odor	Turbidity	TKN
			Column 1*		
0.48	17	22	40	30	
0.96	23	20	50	30	
1.69	27	31	50	53	
2.65	35	33	60	59	
3.37	33	19	60	29	
4.10	38	31	70	31	
4.82	42	26	80	31	
5.54	46	26	90	40	
7.11	51	47	100	69	
8.07	46	45	100	69	
9.64	71	44	100	47	
10.85	79	47	90	63	
12.29	51	44	100	72	
13.98	47	45	100	67	
15.67	41	60	100	77	
16.87	38	51	100	75	
18.08	50	55	100	63	
21.45	40	66	100	76	

continued

TABLE 7 CONTINUED

Cum. Vol Liters	COD	Color	Odor	Turbidity	TKN
		Column 1* (continued)			
24.58	67	50	100	40	
27.23	74	60	100	77	
29.16	89	50	100	71	
31.69	92	67	100	75	
35.55	89	77	100	81	
40.73	101	96	120	91	
		Column 2*			
0.45	4	8	40	18	
0.91	17	6	40	29	
1.59	18	26	40	35	
2.49	27	28	60	29	
3.18	23	19	60	10	66
3.86	25	31	60	37	
4.54	29	21	60	35	26
5.22	34	21	70	10	
6.99	33	37	80	35	
7.60	33	32	90	25	
9.07	51	33	90	38	
10.21	60	42	90	50	79
11.57	36	33	90	42	
13.15	35	38	90	40	
14.74	62	35	100	28	
15.88	57	36	100	70	
17.01	40	39	100	50	
20.19	32	29	100	5	
23.13	52	39	100	30	
25.63	61	25	100	10	
27.44	65	41	100	42	
29.82	77	35	100	45	
33.34	85	54	100	60	
38.33	93	99	100	90	

*Average initial impurities concentration
COD = 4034 mg/l
Color = 333 units
Odor = 10 OII
Turbidity = 69 JTU
TKN = 3,400 mg/l

The percent impurities remaining during the column experiment using FILTRASORB 400 at Q/A = 1.0 and 1.75 gpm/sq ft, for columns 1 and 2 are given in Tables 8 and 9, respectively.

TABLE 8

Percent Impurities Remaining FILTRASORB 400 (Q/A = 1.0 gpm/sq ft)

Cum. Vol Liters	COD	Color	Odor	Turbidity	TKN
Column 1*					
0.72	23	23	56	26	
5.01	37	10	67	44	
7.39	42	9	78	22	
12.16	58	51	78	60	
14.79	52	50	89	60	
16.70	89	55	100	64	
18.60	93	56	100	70	
23.61	71	47	100	50	
26.00	55	53	100	60	
34.82	67	54	100	50	
40.55	78	65	111	75	
44.36	88	77	111	94	
49.85	95	84	111	105	
52.95	98	111	122	129	
57.24	99	123	122	123	
Column 2*					
0.71	12	6	22	5	
3.57	27	12	56	11	
8.33	38	38	67	50	82
10.95	35	37	78	50	
12.85	67	39	89	56	82
14.75	70	45	89	70	
19.75	55	50	100	63	
22.13	46	42	100	62	82
30.94	61	30	100	33	
36.65	63	47	100	63	
40.46	68	50	100	69	
45.93	75	45	110	56	
49.03	88	79	122	97	
53.31	97	100	122	113	92

*Average initial impurities concentration
COD = 3,764 mg/l
Color = 325 units
Odor = 9 OII
Turbidity = 80 JTU
TKN = 2,800 mg/l

TABLE 9

Percent Impurities Remaining FILTRASORB 400 (Q/A = 1.75 gpm/sq ft)

Cum. Vol Liters	COD	Color	Odor	Turbidity	TKN
		Column 1*			
0.81	25	5	50	0	
3.25	43	15	60	20	
11.39	59	41	80	50	
15:46	76	57	100	84	
27.66	70	61	110	90	
39.05	80	77	110	86	
48.81	84	90	110	120	
56.55	85	78	120	96	
60.20	97	98	120	103	
		Column 2*			
0.83	18	0	50	0	55
3.30	30	6	60	0	
11.56	42	33	70	55	
15.69	59	41	90	56	106
28.07	62	52	100	80	
39.63	76	46	110	43	
49.54	80	54	110	64	
57.39	102	78	110	115	130
61.10	97	91	110	96	

*Average initial impurities concentration
COD = 3,667 mg/l
Color = 314 units
Odor = 10 OII
Turbidity = 57 JTU
TKN = 2,732 mg/l

4. Ultraviolet Radiation - Although primarily a disinfection agent, UV can cause some reduction in organic matter content in diluted urine. Two different experiments were conducted to investigate the degree of reduction. In each experiment, one liter of diluted urine was subjected to UV Radiation. The Tables that follow show the percent remaining and initial concentration of impurities for each run after each contact time and before UV, respectively. TKN was analyzed only after 300 minutes contact time. During the second run TKN was not analyzed because the results of the other parameters indicated that it was not necessary.

Percent Impurities Remaining After Ultraviolet Radiation

Run	Cum. Contact Time, min	COD	Color	Odor	Turbidity	TKN
1	30	64	95	92	78	
	90	61	97	83	76	
	180	61	108	83	72	
	300	63	114	92	68	91
2	30	65	87	90	91	
	90	62	88	80	77	
	180	61	109	80	71	
	300	64	113	90	67	-

Initial Impurities Concentration Before Ultraviolet Radiation

Run	COD mg/l	Color Units	Odor OII	Turbidity JTU	TKN mg/l
1	3,956	370	12	50	4,500
2	4,064	300	10	75	-

Disinfection of diluted urine was conducted separately but using the same operational conditions as the other UV Radiation experiments. The Table below presents the percent E. coli remaining after being subjected to Ultraviolet Radiation.

Percent E. coli Remaining After Ultraviolet Radiation

Contact Time, min	Control**	Sample†
30	67	69
90	57	U*
180	56	U
300	52	U

*Undetermined, unable to count the plates using lower dilution rates than control.

**Initial E. coli concentration 9.7 x 10^7.

†Initial E. coli concentration 9.7 x 10^7.

Several researchers have reported that influent treated with Ultraviolet Radiation must be reasonably clear and free from excessive color to allow penetration of the UV light. In view of the results obtained the authors decided to conduct an experiment with clear tap water inoculated with E. coli. Appendix 7 gives the data obtained. The COD of the inoculated tap water was 160 mg/l, Color was 35 units, and Turbidity was 3 Jackson Turbidity Units (JTU). The disinfection of the inoculated tap water was conducted under the same conditions as the disinfection of the inoculated diluted urine. The Table below gives the percent E. coli remaining after the inoculated tap water was exposed to Ultraviolet Radiation.

Percent E. coli Remaining After Ultraviolet Radiation

Contact Time, min	Control**	Sample*†
5	88	69
20	81	63
35	81	31
50	94	13
65	81	25
75	75	0

*Inoculated tap water.

**Initial E. coli concentration 16 x 10^7.

†Initial E. coli concentration 16 x 10^7.

5. Electrolysis - Table 10 shows the various test runs conducted during this phase of the investigation. During runs 1-4 the power inputs were held essentially constant. Samples were taken at the end of each run and interim samples were taken during runs 3 and 4. As can be seen the final product liquids for runs 1-4 possessed an acceptable color reading. These liquids were clear and possessed a chlorine odor without a trace of ammonia. The color readings of the interim samples taken during runs 3 and 4 illustrate the significant extent of the total treatment that occurs during the last 60 minutes of the run.

Test runs 5-9 began with an identical urine volume while power input to the cell was incrementally decreased for each run from 10 amps to 2 amps. As shown, when the amperage was decreased below 6 amps, a satisfactory color reading was not attained signifying a definite power/time relationship for the electrolysis process.

Color was shown to be acceptable depending upon the power/time interval used. When the treated urine possessed an acceptable color, the only existing odor was that of chlorine. The liquid was clear with a free chlorine reading between 2 and 22 mg/l. It should be no problem producing sufficient levels of free chlorine for disinfection purposes.

The test cell itself was too small to provide a sufficient quantity of flush liquid for an actual working sanitation facility. However, it did provide a basis for design of a full scale unit which is currently underway.

TABLE 10

Electrolysis Test Results

Run No.	Sample Quantity (liters)	Amps	Volts	Process Time (min)	Flow Rate (liters/min)	Color (Cobalt Units)	Chloride (mg/l)
1	1.0	10	16-18	120	1.0	35	1,560
2	4.0	10	16-21	630	1.0	75	3,120
3	1.0	10	16-20	120	1.0	450	300
3	1.0	10	16-20	180	1.0	50	158
4	1.0	10	16-20	210	1.0	450	954
4	1.0	10	16-20	270	1.0	45	150
5	0.5	10	16-18	90	1.0	45	252
6	0.5	8	16-18	120	1.0	20	505
7	0.5	6	16-17	155	1.0	30	291
8	0.5	4	15-16	190	1.0	125	2,230
9	0.5	2	14-15	240	1.0	300	2,740

Run No.	Total Dissolved Solids (mg/l)	Chemical Oxygen Demand (mg/l)	Free Chlorine (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Total Organic Carbon (mg/l)	pH
1	14,310	2,510	2.3	66	1,030	3.70
2	16,600	3,500	3.0	2,150	2,270	5.75
3	18,920	7,980	0.2	2,700	4,610	5.30
3	24,150	3,260	10.0	650	1,580	1.75
4	22,810	9,800	0.5	1,020	4,990	5.30
4	21,840	3,880	15.0	290	2,420	1.60
5	16,740	3,570	22.0	250	1,700	1.85
6	17,080	4,640	20.0	450	1,760	2.02
7	18,620	1,670	12.0	280	1,450	1.90
8	18,990	3,570	3.0	720	2,030	2.30
9	16,210	4,180	0.35	2,800	2,550	6.10

6. Physical/Chemical Process Train - Indepth operational parameter testing for this alternative is underway at present. This series of processes were originally intended as merely a field expedient method to be used prior to development of an actual prototype flush liquid recycling system. However preliminary results thus far show acceptable quality liquid may be produced for reasonable periods of time. Testing currently underway will compare water quality results from this alternative with the other previously tested urine treatment methods.

SUMMARY AND CONCLUSIONS

The several different processes that have been tested to date serve to illustrate the problem of establishing flush water quality criteria. Carbon adsorption appeared to be the most acceptable of the initial set of processes tested. However the potential for obtaining replacement carbon through the advanced base logistic systems makes it a poor choice.

The electrolysis process developed by NASA appears to be excellent as a control on color, odor and disinfection. However engineering a self-operating system poses a challenge. An experimental prototype is under development.

The physical/chemical process has to date retained its long standing place in the flush toilet world. However the logistic problems associated with delivery of chemicals continues to give priority to engineering the electrolysis systems or developing a new approach.

The Table that follows summarizes the average percent removal of impurities by the unit treatment processes evaluated in the first series.

Summary of Average Range of Percent Impurities Removal

Method	COD	Color	Odor	Turbidity	TKN	Coliforms
Ozonation	19-39	23-93	22-46	18-93	0-6	27-100
Ozonation-UV	26-55	18-91	21-51	22-91	0-2	45-100
UV	35-36	0-9	0-9	15-32	0-9	0-31
			Carbon Adsorption			
NUCHAR WV-L	66-83	69-78	45-60	21-88	19-74	-
FILTRASORB 400	65-80	86-95	39-60	75-90	45-80	-

ACKNOWLEDGMENT

The authors wish to acknowledge Dr. Henry Van for his diligence in performing the tests on the initial four processes involving Ozone, UV and Carbon. Professor George W. Reid of the University of Oklahoma is particularly recognized for the fundamental mechanical concept of the field head unit. His stimulation to Dr. Van and the Civil Engineering Laboratory on the water reuse experimentations are of special note.

Expeditionary field head module is shown below, Figures 1 & 2.

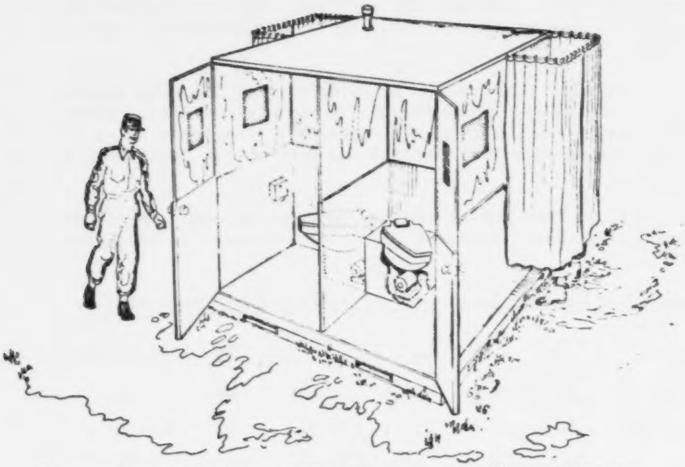


Figure 1. Front View of Expeditionary Field Head Module.

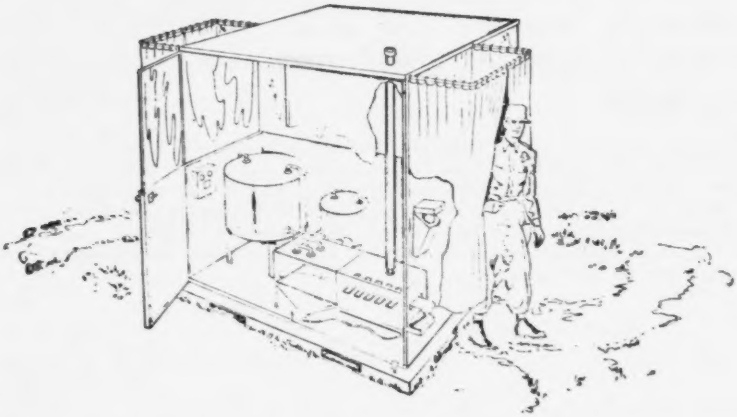
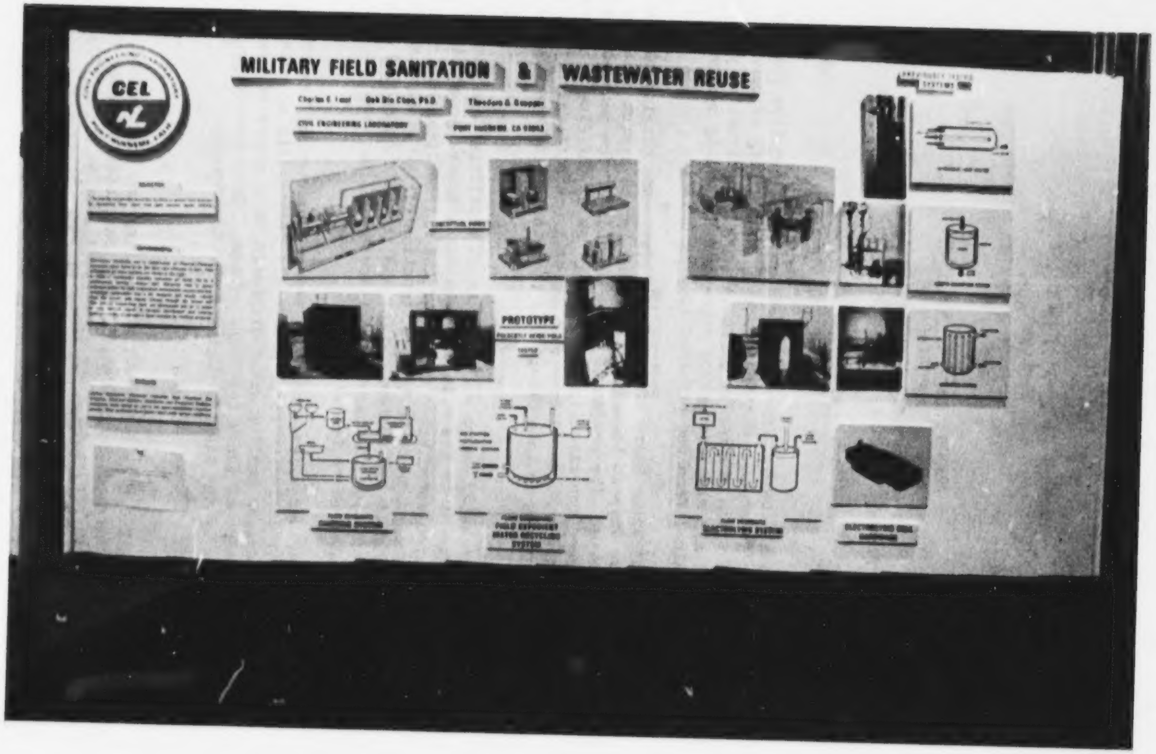


Figure 2. Rear View of Expeditionary Field Head Module.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MILITARY FIELD SANITATION & WASTEWATER REUSE
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PROTOTYPE

POWER PLANT CONDENSER COOLING WATER AS A WATER SUPPLY SOURCE

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GENERAL

The Niagara Mohawk Power Corporation owns and operates five fossil-fueled electric generating stations located in the City of Oswego, New York, and a sixth station is currently under construction at the same site. All six stations employ once-through cooling systems, with water obtained from and returned to Lake Ontario.

The Metropolitan Water Board of Onondaga County, NY, obtains its water supply from Lake Ontario through an offshore intake system owned by the City of Oswego. The projected water demands of the Metropolitan Water Board exceed the capacity allocated to it by the City of Oswego, and the Board has considered construction of two additional offshore water supply intakes in Lake Ontario in the vicinity of the City of Oswego.

The Metropolitan Water Board water treatment facilities are located west of and adjacent to the site of the Niagara Mohawk generating stations. The projected water demand of the Metropolitan Water Board was recognized prior to the construction of the Niagara Mohawk Unit No. 5, which is the westerly unit, and it was constructed with an optional connection for discharge of spent cooling water to the Metropolitan Water Board facilities.

This paper describes a research study being conducted by Lawler, Matusky & Skelly Engineers to determine the feasibility of using the Unit No. 5 condenser cooling water discharge as a source of raw water to the Metropolitan Water Board system. The research program is being funded by the Niagara Mohawk Power Corporation.

QUANTITIES

Generating Unit No. 5 is a "base-load" station and operates at loads approaching full-rated load. Under rated load, cooling water flow is 435 cfs (12.32 m^3/sec) with a temperature rise of 30 F (16.7 C). The intake is located approximately 800 ft (244 m) offshore, and the discharge to the lake is via a multiple port diffuser designed to limit water surface temperature rise in accordance with environmental standards.

Under winter conditions, the raw cooling water is "tempered" by mixing of a portion of the heated water discharge to avoid ice formation on the intake screens and related equipment; such "tempering" reduces the volume of cooling water drafted from the lake.

The City of Oswego's intake is located approximately 1.16 miles (1.86 km) offshore; there is no convenient method of avoiding ice-related problems under winter conditions. The Metropolitan Water Board currently draws approximately 26 mgd (40.3 cfs, 1.14 m^3/sec) from the Oswego intake, and projected future demand is approximately 60 mgd (93 cfs, 2.63 m^3/sec), in addition to the demands of the City of Oswego.

The heat added to the Unit No. 5 cooling water is 2,932 million Btu/hr, (733 million Kg-C/hr), or 70,357 million Btu/day (17,589.3 million Kg-C/day). At present, this added heat is being discharged to Lake Ontario, and is considered a form of pollution; in fact, it is an expensive resource which is being misplaced (at additional expense) for want of an effective method of utilization.

The present 26 mgd (1.14 m^3/sec) draft of the Metropolitan Water Board, at 30 F (16.7 C) temperature rise would incorporate 6,505 million Btu/day (1626.3 million Kg-C/day), and the projected 60 mgd (2.63 m^3/ sec) draft would incorporate 15,012 million Btu/day (3,753 million Kg-C/day) in the raw water supplied to the system. The added heat content of the 60 mgd raw water supply is equivalent to 712,000 barrels of oil annually, at 100% efficiency. Unfortunately, the heat is "low-grade," in that the temperature of the water is normally below 90 F (32 C). Nevertheless, the total quantity of heat is large and justifies significant effort to recover and utilize as much of it as possible.

RESPONSIBILITIES

Both the Metropolitan Water Board and the Niagara Mohawk Power Corporation are "single-purpose" institutions. The duty and responsibility of the Metropolitan Water Board are the supply and delivery of potable water to its present and projected service areas reliably and economically. The duty and responsibility of the Niagara Mohawk Power Corporation are the supply and delivery of electric power to its present and projected service areas reliably and economically.

While the above-stated duties and responsibilities are obvious and certainly are not unique to these institutions, they do tend to create a management emphasis which often excludes all other considerations. Cooperation among institutions organized for different "single-purposes" is relatively rare; the opportunities for such cooperation are probably very frequent, but are seldom recognized or defined for want of a sponsor. When such opportunities are recognized, they are often so poorly defined none of the prospective cooperators can justify participation for fear of the additional impediments to carrying out their basic duties. As a further complication, cooperation among institutions is a fruitful source of delay; decisions to commit large amounts of capital are usually not made hastily, and usually do include a schedule for execution which is cleanly efficient. The opportunity for a cooperative effort must be known before the time of decision, making the definition of any but the most obvious opportunity very difficult.

The present research study is directed to define an opportunity for cooperative effort by two "single-purpose" institutions. The opportunity exists largely as a result of the Niagara Mohawk construction of Unit No. 5 with the optional connection permitting discharge to the Metropolitan Water Board without interfering with power generation.

The cooperative effort, to be successful, must be based on mutual recognition and understanding of the basic duties and responsibilities of each participant. In this case, the Metropolitan Water Board draft of cooling water must not interfere with nor inhibit power generation; the Niagara Mohawk operations must not interfere with nor inhibit the supply of treatable raw water to the water treatment facilities.

Similarly, in a successful cooperative effort, the benefits resulting from that effort should be shared. In this instance, both institutions serve the public in a general sense; however, the Niagara Mohawk customers are a different (and larger) group than the Metropolitan Water Board customers, so that an equitable sharing of benefits between participants will allow reasonable distribution of those benefits to the differing customer groups.

One of the benefits, the reduction of environmental impacts, probably cannot be allocated only to the participants and their customers; that benefit accrues directly to the public at large.

RELIABILITY

Generating Unit No. 5 is designed to operate at a high level of reliability. While the major elements (boiler, turbine) are nonredundant, accessory elements (cooling water pumps, feedwater pumps, and the like) are provided with redundant units to assure reliability. In general, Unit No. 5 is designed as an element in a power generation system; redundancy for the Unit No. 5 as a single entity is provided by the system. However, Unit No. 5 requires a high level of reliability to serve the system properly. System operations may be directed to permit shutdown of Unit No. 5 at intervals for servicing and maintenance of the nonredundant elements; such shutdowns may be scheduled in advance and are certain to occur.

The Metropolitan Water Board water treatment, transmission, and distribution system meets current reasonable standards for system reliability. In general, pumps, treatment units and related accessory equipment are redundant elements; system operation continues while specific units are shut down for repair or maintenance. Certain major elements of the system (the transmission main from Oswego to the service area, major distribution mains, reservoirs) are nonredundant. A break in the transmission main would require supply from the reservoirs pending completion of the repairs; a reservoir out of service would require more sensitive operation of the transmission and distribution mains.

While the Metropolitan Water Board water system is not interlocked with other water systems in the manner Niagara Mohawk Unit No. 5 is connected to the power grid of the region, the water system major elements interact within the water system in a similar manner. Each system is designed to provide reliable service; each reacts and responds to system as well as to local requirements.

For the Metropolitan Water Board, continuous access to the raw water supply is essential; the water source is the "redundant" element in the event a reservoir is inoperative. Thus, that access cannot be dependent upon Unit No. 5 operations, since it is known that Unit No. 5 will be nonoperational occasionally, albeit infrequently and for short periods.

For Niagara Mohawk, operation of Unit No. 5 cannot be dependent upon a continuous draft of water by the Metropolitan Water Board. The water system may find it desirable to suspend treatment operations on occasion, for whatever reason, so that Unit No. 5 operations cannot be dependent upon continuous draft by the water supply.

The connection arrangement constructed by Niagara Mohawk is at the entry to the cooling water discharge tunnel. At that point, the heated cooling water has no further value or use to Niagara Mohawk, having fulfilled its function. Any water not drafted by the Metropolitan Water Board will be discharged to the outlet diffuser and the lake; almost all of the cooling water could be delivered to the water system without affecting Niagara Mohawk, so long as the water needed for "tempering" during winter remained available to the generating station.

During periods when Unit No. 5 is not operational, the water supply requirements can be satisfied by the use of the cooling water discharge diffuser and tunnel in reverse flow mode. Under such conditions, the raw water will be at lake temperature, 25 F (13 C) to 30 F (17 C) colder than normal. Thus, the Metropolitan Water Board system cannot be dependent upon delivery of heated water; the warmer water is to be considered a routine benefit, but not an absolute necessity.

WATER QUALITY

A review of existing water quality data has been conducted to discover any water quality differences that would preclude using water drawn by Niagara Mohawk Unit No. 5 from the nearshore area in place of water drawn by the existing City of Oswego intake from farther offshore.

The New York State Department of Environmental Conservation maintains a grab sampling station at the City of Oswego's existing intake, and their data on about 30 parameters over the period 1964-71 have been reported by the U. S. Army Corps of Engineers in their draft Environmental Impact Statement on Oswego Harbor (March 1975). Lawler, Matusky & Skelly Engineers have reported nearshore water quality data obtained during aquatic ecology studies for the Niagara Mohawk Power Corporation over the past several years.

The data obtained in the Niagara Mohawk aquatic ecology studies are effectively equivalent to the City of Oswego's existing intake water quality, except for sodium concentration. A mean sodium concentration of 1.06 mg/l (Na) was found for 54 samples of the Oswego intake, while the mean sodium concentration in the vicinity of the intakes for Niagara Mohawk Units 1-5 is about 16 mg/l (Na); the increased sodium concentration is believed due to the closer proximity of the mouth of the Oswego River, which is known to have high sodium chloride concentrations attributed to the effects of Lake Onondaga. While the sodium concentration is well below the maximum considered acceptable in a good raw water supply, a more detailed study of sodium concentration is planned as part of the present research program.

Thus, the first-phase analysis of water quality data has not found any water quality parameter which would preclude substitution of Unit No.5 cooling water for the raw water presently supplied via the City of Oswego's intake.

It should be understood that the examination of water quality data conducted to date has been limited to existing data. Subsequent phases of the research program include detailed analysis of the cooling water delivered to the Unit No. 5 outlet to establish conclusively whether or not it is of a quality suitable as a source of water for a municipal water system.

The concept of using spent water as a water supply source includes the assumption that the cooling water discharged will not be polluted in any manner; the only acceptable difference between the intake and outlet water quality is the increase in temperature. In order to make that assumption a reality, Niagara Mohawk must avoid discharge of any wastewater streams to the Unit No. 5 cooling water system. Because of the proximity of Unit Nos. 1, 2, 3, 4 and 6, direction of any wastewater streams to the outlet systems of those units poses no hardship or significant difficulty.

WATER QUALITY STANDARDS

At present, water supply quality standards appear to inhibit the use of water employed for any other purpose as a source of raw water. In limited terms, such a standard is reasonable since it helps to preclude any pollution of the source. However, such a broad standard should not be applied without thorough analysis of the specifics of each situation, but should serve as a general guide to a decision based on the specific conditions of a proposed water supply.

In some respects, existing water supply quality standards are the result of the management emphasis on the "single-purpose" of the water supply, rather than a recognition of the facts associated with a specific supply source. If water reuse is to be pursued successfully in any context, the operative water supply quality standards should be those which relate realistically to the specific situation.

The duties of the regulatory body having jurisdiction over the local water supply utility should include establishment of safe and realistic standards for each source. As our national resources become subject to increasingly intensive use, the need for establishing specific standards will become increasingly apparent. Sound and safe regulation can only be obtained by examination of the merits of each proposal in detail.

WARM WATER EFFECTS

The concept of supplying customers with warm water in place of water at natural source temperature is relatively recent. Some opposition to the concept may be expected, if only because it is normal to resist change. The research program is directed to identify the effects upon the utility and customer water supply installations when water is supplied at temperatures 20 F to 30 F (11 C to 17 C) higher than in the past.

(a) Warm Water Effects on Water Utility System:

1. Avoidance of intake-icing problems in cold weather.
2. Natural self-disinfection processes accelerated. (1)
3. Reduction of density and viscosity of water accelerates settling, permits more rapid filtration, and requires higher backwash rates. (1)
4. Alum precipitation and flocculation may be more efficient. (1)
5. Shorter survival period for pathogens. (1)
6. Generally supports higher proportion of blue-green algae. (1)
7. Reduces prospect of frozen mains in cold weather.
8. Reduces icing problems in reservoir and storage tanks. (1)
9. Increases rate of chlorine demand. (1)

(b) Warm Water Effects on Domestic Customers

1. "Cold" water tap produces "lukewarm" water- (a cold drink will require a water bottle in the refrigerator).
2. Reduces energy consumption and costs of heating hot water.
3. Reduces hot water needs-(many "mixed hot and cold" uses will be satisfied by water from the "cold" tap).
4. A "cold" shower will be warmer.
5. "Cold" laundry cycle supplied with warmer water.
6. Pipe and toilet tank "sweating" eliminated.

(c) Warm Water Effects on Non-Domestic Customers

1. Reduces energy consumption and costs of heating water.
2. Reduces hot water volume requirements.
3. Eliminates "sweating" of cold water lines, etc.
4. Increases costs of "water-cooler" operation.
5. Increases costs of cooling processes dependent on water temperature (but would have limited effect on cooling-tower makeup).

The above preliminary lists of the effects of supplying warm water are presented objectively, but public reaction may be expected to be subjective. Those who are energy-and-cost-conscious will consider the conserved energy and reduced expenditures ample reward for the other adjustments in living habits; others may object to the inconvenience of obtaining a cold drink of water from the refrigerator, and some may consider the lack of a cold shower critical.

The effects upon the water utility system are largely beneficial; the one prospective problem is the possibly greater proportion of blue-green algae in reservoirs. With water supplied at "natural" temperatures, such a condition would prevail only in warm weather; with warm water supply, the problem periods could extend over most of the year.

The effects upon non-domestic customers will vary, dependent upon their water use arrangements. Since hot water is used in many processes, it is probable that the supply of warm water will be beneficial; however, some customers may be inconvenienced or suffer increased costs.

On balance, the supply of warm water should be beneficial, since it will conserve energy and reduce hot water heating costs. Most of the disadvantages of the warm water supply relate to subjective inconvenience, rather than to economic loss.

It should be recognized that present water use habits and customs in the United States were evolved from acceptance of economic constraints. Probably no one ever made an effort to determine the desirable delivery temperature of the water supply, so long as it was above 32 F (0 C). Any suggestion that it would be more desirable to deliver water at a temperature different than that of the source would face criticism due to the cost of heating or cooling the entire supply. This research study also recognizes that the source temperature will control; the objective is to evaluate the feasibility of delivering water from a warm source, not to determine the most desirable temperature of the water supply.

The information necessary to estimate specific cost reductions to typical water customers is being collected.

DELIVERY TEMPERATURE

While the Unit No. 5 cooling water discharge temperature is expected to be 25 to 30 F (14 to 17 C) higher than lake water temperature, some temperature drop will occur as the water is treated, conveyed, stored, and distributed. In general, the heat losses through the system will vary with the difference between water temperature and the ambient temperature of the surroundings; however, in practical terms, the heat losses will not vary widely. The water temperature drop will also be dependent upon the quantity of water passed through the system, with a greater temperature drop associated with a lesser quantity.

This research study will include an evaluation of the several heat losses, and the effects thereof upon water temperature at the point of use. The detailed water system data needed for such an evaluation are now being obtained.

Preliminary computations indicate that a municipal water system is not an efficient heat sink. For example, the 54-in (137-cm) diameter transmission line from Oswego to the Metropolitan Water Board service area is 25.8 miles (41.5 km) long, with rated capacity of 30 mgd (1.32 m^3/sec). At rated flow, and 40 F (22.2 C) differential between water and surrounding soil, the temperature drop is computed at about 1 F (0.6 C). At one-half rated flow, the temperature drop would be about 2 F (1.1 C). A similar loss may be computed for the major distribution mains, except that the flow in each such main is subject to variation during the day. With no flow in the pipe, the warm water would lose about 0.1 F (0.06 C) per hour, or about 2.4 F (1.3 C) per day.

The preliminary computations indicate that a total temperature drop of 5 to 10 F (2.8 to 5.6 C) would not be unreasonable with normal operation of the water system. Thus, some 20 to 30% of the heat added to the raw water may be lost during treatment, storage, and distribution;

or, more realistically, 70 to 80% of the heat remains to provide a community benefit.

ENVIRONMENTAL IMPACT

With separate intakes, as at present, both the Metropolitan Water Board and the Niagara Mohawk Power Corporation are causing some impact upon the aquatic biota of the lake.

The municipal water supply intake delivers the water and entrained biota to the water treatment system, in which the biota are (of necessity) removed and destroyed in the treatment process. This environmental impact is unavoidable; even without treatment, the normal water use would result in equivalent destruction of the biota.

The Niagara Mohawk Unit No. 5 intake also entrains biota, some of which are destroyed and some of which are adversely affected by passage through the cooling system. Despite efforts to minimize destruction of biota, some does occur.

By using the Unit No. 5 cooling system as a water supply intake, the total impact is reduced significantly, since the total destruction of biota due to the water supply intake is eliminated; but the Unit No. 5 intake discharges fewer survivors to the lake, due to the diversion of a part of the cooling water discharge to the water supply.

In addition, the quantity of heat discharged to the lake is reduced, lessening that undesirable impact.

In respect to environmental impact, the desirable combination would be a power station cooling system discharging all cooling water to a water supply. Under such conditions, the aquatic impacts of the power station operation would disappear; the remaining impact would be the unavoidable destruction of the biota associated with a water supply.

While it may be difficult to achieve the ideal situation, a significant fraction of the ideal will produce a proportionate environmental benefit.

In addition to the reduced environmental impacts of a jointly used intake, the environmental impact associated with the construction of the second intake is also avoided, along with a significant capital cost.

ECONOMIC BENEFITS

The use of Niagara Mohawk Unit No. 5 as a water supply source for the Metropolitan Water Board system avoids the need for a separate intake in Lake Ontario, together with onshore pumping and transmission facilities.

The intake which may be so avoided was described in the Onondaga County Water Supply Study of 1968 (2) and consisted of an intake at Burt Point, together with associated pumping station and related facilities. The construction cost of the intake alone was estimated at $2,000,000 in 1968; at present construction costs, $4,000,000 would not be unrealistically high. The prospective economic benefit to the Metropolitan Water Board customers in reduced capital costs alone is significant. When added to the reduced cost of heating water, the total economic benefits accruing to the water system customers are worthy of public support.

CONCLUSION

The above discussions describe the objectives and current progress of a research program to determine the feasibility of using power station condenser cooling water as a municipal water supply source. While the research effort is directed primarily to defining the conditions of cooperation between the Niagara Mohawk Power Corporation and the Metropolitan Water Board of Onondaga County, NY, the findings will also provide information useful in evaluating similar cooperative efforts at other sites.

One of the findings is that this type of opportunity is more accidental than planned. The progress of the research to date indicates that the prospective benefits are of a magnitude to justify planning.

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REUSE OF WASTEWATER CONTAINING FIREFIGHTING AGENT

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Firefighting training at Military bases consumes considerable amounts of water and a type of firefighting agent, named Aqueous Film Forming Foam (AFFF). The AFFF consists of fluorochemical surfactant, hydrocarbon surfactant, solvents (such as ethylene glycol and its derivatives, butyl carbitol, etc.) and water. During firefighting exercises (including equipment function test), a 3.5% to 6% solution of the AFFF concentrate is used alone, or in a combination with purple K powder (PKP, potassium bicarbonate).

Wastewater generated from such firefighting exercises contains the AFFF stock constituents, residual fuel oil and gasoline, combustion products, and suspended solids. All these constituents are considered to have some adverse effects on the receiving environment. Toxicity study results indicated that AFFF alone has a 48-hour TLm of 150 ppm (v/v) to oyster larvae. An activated sludge process could take up to 200 ppm AFFF (v/v) with no apparent reduction in performance efficiency.

Research efforts have been directed toward developing a cost-effective treatment and disposal method for the AFFF-laden wastewater. An oil-water separation followed by clarification (such as sedimentation, filtration, centrifugation, and/or air flotation) with or without chemical coagulation appeared to effectively remove residual fuel oil and gasoline and suspended solids. Additional treatment however, deemed necessary in order to meet at least 150 ppm (v/v) oyster larvae toxcity criterion.

Ozonation, carbon adsorption and membrane processes have been investiged for the additional treatment alternative. Experimental results are reported hereafter.

EXPERIMENTAL PROCEDURES AND METHODOLOGIES

1. Ozonation- In the ozonation studies the batch vessel used was a 4-l New Brunswick fermentor (New Brunswick, NF). Dried oxygen feed through a T-408 Welsbach ozone generator (Philadelphia, PA) was the source of ozone. A constant temperature of 25°C was maintained by cooling/heating coils running through the vessel. The impeller speed was fixed at 480 rpm. The pH was not controlled. The feed gas had a flow rate of 4 l/min and ozone concentration of 20 mg/l. The fermentor was equipped with a 15-w low pressure mercury germicidal lamp (UV catalyst) (General Electric, Schenectady, N.Y.).

A 25-ml or 50-ml sample was drawn every 15 or 30 minutes for two and one-half hours. Residual ozone was determined immediately by quenching with sodium thiosulfate crystals. The samples were then refrigerated at 4°C for analysis of TOC later.

Dissolved ozone concentration was determined intermittently using the Schechter method for high ozone concentration. Five ml of sample were drawn off with a glass syringe already containing 5 ml of 2% KI for instananeous reaction. After 30 minutes the mixture was analyzed for absorbance on a Bausch and Lomb Spectronic 20 (Rochester, NY) at 352 nm.

Feed gas concentration was determined by diverting a portion of the flow through a sample line. The ozone was bubbled through a vessel containing 400 ml of 2% KI where it is converted to O_2. The gas flow continued through a wet test meter. After 3 l of gas had passed, the sample line was closed. The KI solution was acidified with concentrated HCl below pH 2 and titrated with 0.1 N $Na_2S_2O_3$ using starch as an indicator.

2. Activated Carbon Adsorption - The activated carbon adsorption experiments were conducted with Calgon Filtrasorb 400 activated carbon (Pittsburgh, PA). Size range consisted of particles which passed a U.S. standard sieve No. 14 but were retained on a No. 40 sieve. After sieving, the carbon was washed thoroughly with dionized water to remove fines. Then the carbon was dried for at least 48 hours at 105°C.

In the kinetics study, 1000 mg of activated carbon were put in a 1-liter beaker with 1000 ml of 0.1% AFFF. A sufficient rpm was maintained to induce mixing without fragmenting the carbon particles. A 5 ml sample was pipetted at 0, 10, 20, 30, 45, 90, 120 and 150 minutes and immediately analyzed for TOC.

For the isotherm study 100-ml samples of 0.1% AFFF were placed in nine French square bottles. Activated carbon of weight 0, 50, 100, 150, 200, 300, 400, and 600 mg were added to each bottle and the bottles sealed. The samples were agitated for three days and analyzed for TOC upon filtration through a 0.45 u millipore filter (Bedford, MA).

The activated carbon column utilized in this study was a 12-inch length and 1-inch inner diameter plexiglass column. 35 grams of carbon were packed to a height of 6.5 inches with glass wool for support. This column diameter to particles size ratio of approximately 30 minimizes wall effects. 0.33% Ansul was applied at a rate of 4 lph. Samples were taken every 15 or 30 minutes and analyzed immediately for TOC.

3. Reverse Osmosis (RO) and Ultrafiltration (UF) - A full size Dupont B-10 module (5' x 5" dia.) having a salt (NaCl) rejection of 99% and a permeation rate of 13,626 lpd (or 3,600 gallons per day) at 42.19 Kgf/cm^2 (or 600 psig) was employed for RO study. The feed flow rate through the module was 15.14 lpm (or 4 gallons per minute). The temperature was maintained at 25°C. A 1% AFFF stock solution or the UF permeate of AFFF wastewater was used as feed.

A pilot-scale UF system consisting of 4 abcor 5' x 1" tublar membrane was used for UF experiments. Two of these tubes were lined with Abcor HFA-D membrane and the other two with Abcor HFA-F membrane. The feed flow through these tubes was 60.56 lpm (or 16 gpm) at 1.93 Kgf/cm^2 (or 27.5 psig). The temperature was maintained at either 25°C or 50°C.

Two types of experiments were conducted; namely, the differential test and the batch feed test. In the differential tests, the permeate from the membrane module is returned to the holding tank, thus maintaining a constant concentration of the feed in the tank. This test permitted the evaluation of the dependence of membrane performance in terms of both flux and rejection with time at a given feed concentration. In the batch feed test, the permeate is continuously discarded and the feed is allowed to concentrate to a predetermined level in the holding tank. This test procedure is used to determine the dependence of membrane performance on feed concentration level. The differential test was used for evaluating 1% AFFF stock solution, whereas the batch feed test for the direct discharge wastewater.

EXPERIMENTAL RESULTS AND DISCUSSIONS

1. Ozonation of RO Permeates - The TOC of the RO permeate of FC-206 and Ansul were relatively low being 11 and 6, respectively. The dissolved ozone concentrations were greater than 0.5 mg/l all the times except at the beginning. Thus the reactions were not conducted under ozone mass transfer limited conditions.

Figures 1 and 2 show no removal of TOC by ozone without UV catalyst using RO permeate of either FC-206 or Ansul (Trade names for commercial AFFF product) Upon application of the UV catalyst, however, TOC dropped to very low values following a first order kinetics (see Figures 1 and 2).

Determinations of COD of the ozonated RO permeates were not possible except for the initial permeate (T=0). Ozonated sample precipitated with the addition of Hg_2SO_4 and H_2SO_4. Normally this would indicate chlorine was freed by oxidation. However, no chlorine was present in either product according to information available from the manufacturers.

The pH of the permeates rose from 7.1 to 8.4 (FC-206) and 6.8 to 9.7 (Ansul) with the UV catalyst, while the pH fell from 7.1 to 6.4 (FC-206) and 6.8 to 6.3 (Ansul) without UV catalyst during ozonation. Since the resulting RO permeates have extremely low alkalinity, the pH is very sensitive to changes in the nature of the organic compounds during ozonation with UV. The slight decrease in pH during ozonation without UV may be a result of CO_2 obsorption from the sparged gas and/or from the surrounding atmosphere.

2. Activated Carbon Adsorption - Kinetics and isotherm studies were conducted on FC-206 and Ansul. Figure 3 shows both followed second order kinetics with FC-206 getting better adsorption. FC-206 shows a 60% removal of TOC at 152 minutes compared to 40% removal from Ansul (Figure 3). Isotherms are presented in Figure 4. The area under the isotherms curve is indicative of the capacity of adsorption. The broader curve of FC-206 thus indicates again a better adsorption. This can be explained by having a higher MW diethylene glycol monobutyl either in FC-206 compared to a lower MW and more polar compound glycol in Ansul as shown by an earlier eluted gas chromatograph peak from Ansul. The GC peak

of Ansul appeared at 4.58 min as compared to that of FC-206 at 5.99 min. Carbon was a high affinity for high-molecular-weight glycol ethers. The surfactants being hydrophobic should be readily adsorbed from both solutions.

The column study of stock Ansul solution shows better adsorption than theoretically determined based on isotherm data (Figues 5 and 6). This could be due to the greater concentration of Ansul in the column run as compared to the batch run. The column showed uptake of 0.11 g TOC/g carbon as opposed to 0.08 g TOC/g carbon theoretically. The column study with a coagulated (with 300 mg/L of alum) equilization pound AFFF-laden wastewater showed uptake of 0.10 g TOC/g C.

The constants for the Freundlich isotherms were determined based on Figure 5. They are summarized in the following:

	Ansul	FC-206	
	TOC up to 60 ppm	TOC>10 ppm	TOC<10 ppm
K	0.033	0.38	0.024
n	1.45	7.27	0.765

where $\frac{X}{M} = KC^{1/n}$

Combined coagulation-activated carbon showed excellent initial removal (Figure 7). 'Plateau' effluent had only 0.004% glycol or 80% removal. MBAS was undectable. The TOC was only 7 mg/l.

3. Reverse Osmosis (RO) and Ultrafiltration (UF)

Performance of UF and RO in Treating AFFF Aqueous Solution - The purpose of these experiments was to study the potential of using membrane processes to recover the active ingredients in the AFFF concentrate for reuse. The membrane ultrafiltration (UF) process is intended to be used to remove all of the debris from firefighting exercises. These include suspended solids and floating oils. It can be seen from Table 1 that no more than two percent of the TOC materials in AFFF concentrate is retained by the UF process. The small rejection of TOC may be a result of TOC retaining through excessive foaming. The UF process literally allows the passage of all of the active ingredients in the AFFF wastewater (Table 1) and retains most of the debris in the wastewater. This is plausible since all of the active ingredients can be separated from the debris, and can later be recovered by a subsequent RO step. The fluxes determined with the UF membranes using 1% AFFF aqueous solutions are very encouraging. Up to 36.83 $1/M^2$/day (or 104.7 gallons per day per sq ft) was obtained which could render the process economically feasible.

A 1% stock solution of FC-206 and Ansul K74-100 was used to evaluate the reverse osmosis (RO) process. Better than 9% of the active ingredients, such as TOC, glycols, surfactants, etc., can be retained by the RO membrane. Due to the good removal of surfactants, fluorocarbons are also excepted to be rejected by RO at high levels. In view of the high product value of the AFFF stock solution and a good retention of the active ingredients, RO process appears to have merit in concentrating the UF permeate for reuse of the AFFF solution. The ozonation process may be needed to treat the RO permeate prior to discharge into the receiving stream. However, if seawater were used to dilute the AFFF stock solution, RO recovery of the AFFF solution may not be applicable due to the accumulation of total dissolved solids, TDS (mainly NaCl, see Table 1 for NaCl rejection), in the RO concentrate. The permeate flow rates through the B-10 module at 42.19 Kgf/cm^2 (or 600 psig) are typical to those specified by Dupont (Wilimgton, DE).

Table 1
Performance of Ultrafiltration of Reverse
Osmosis Processed in Treating AFFF Aqueous Solution

Parameter	Ultrafiltration	Reverse Osmosis
Rejection, %		
NaCl, 0.5%	0	99
TOC		
FC-206, 1% Solution	1.8	98.7
Ansul, 1% Solution	1.5	99.4
Glycols		
DEGMBE (FC-206)	0	99.4
Unknown (Ansul)	0	99.7
Flux		
FC-206, 1%	36.83 l/m^2/day	13626 lpd
Ansul, 1%	29.41 l/m^2/day	13626 lpd

Performance of UF and RO in Treating Actual Firefighting Excerise Wastewater

UF Process - Two experiments were done with a direct discharge wastewater. All conditions were identical in both runs, except the temperature of the wastewater. The first experiment was run at a temperature of 25°C and the second at 50°C.

The treatment of the direct discharge wastewater with the ultrafiltration process showed inconsistent rejection of TOC and glycols as observed with the 1% Ansul AFFF solution. This is probably due to the same reason of having excessive foaming. The overall rejection of glycols can be assumed zero since they went all the way from negative to positive rejections. Table 2 shows the results of this experiment.

The big difference between the ultrafiltration experiments treating the direct discharge wastewater and the 1% Ansul solution was in the flux. The flux with the wastewater was much smaller than the one with the 1% solution. This was expected since the wastewater contains a lot of other materials that can reduce the flux of the system.

Table 2
Membrane Rejection, Ultrafiltration Process in
Treating the Direct Discharge Wastewater

Parameter	% Rejection
TOC	3.35 to 16.90
Glycols	-14.89 to 10.65

From Figures 8 and 9, the importance of the operating temperature in the ultrafiltration process can be seen. The flux at 50°C is almost double of that at 25°C, and it seems to approach a constant value. In contrast to the flux at 50°C, the flux at 25°C seems to be decreasing toward a zero value. The difference in flux caused by the different operating temperature can be attributed to the reduction in viscosity at higher temperature. The effect of concentration of the feed at 50°C can be calculated using Figure 10. Figure 10 is quite useful to estimate the flux of UF at higher feed concentrations.

A yellow color was noticed in the ultrafiltration permeate. This color is probably caused by some combustion products that passed through the membrane. The overall quality of the permeate was very good. It was free from any suspended solids and debris from the firefighting excerise.

RO Process - The permeate from the ultrafiltration experiment run at 50°C was saved and used as the feed solution for the reverse osmosis process. The results of the reverse osmosis treatment of UF permeate were as good as what was obtained with the 1% AFFF solution. Over 99.5 percent reduction in TOC, surfactants, COD, glycols, and conductivity was obtained. The permeate was clear and colorless. The compound that contributed to the yellow color in the feed was rejected completely by the reverse osmosis membrane.

A composite sample of RO permeate was analyzed for TOC. It contained 17 mg/l of TOC. According to Table 3, this TOC would imply a maximum COD of 54 mg/l. If complete treatment of RO permeate is required for reuse, ozonation of the permeate with the aid of ultraviolet catalyst can reduce the TOC to an insignificant level.

One of the objectives of this reverse osmosis process is to achieve a 10-fold volume reduction in the holding tank. Since the holding tank of the experimental system was not big enough, the desired volume reduction could not be achieved. Anyhow, the flow of permeate at the 10-fold volume reduction can be predicted using a semilog plot as shown in Figure 11, since permeation flow was found to decrease exponently vs. feed concentration.

The high rejection of the active ingredients in AFFF by the reverse osmosis membrane makes it possible for reuse of the concentrate in the firefighting exercises. However, there appears to accumulate fluoride in the UF concentrate. The fluoride concentrations of the direct discharge wastewater and UF concentrate (approximately tow-fold concentration) were found to be 100 ppm and 160 ppm, respectively. This implies that the fluoridecarbons are removed simultaneously along with the surfactants that are assumed in emulsifying the unburned jet fuel. The loss of fluorocarbons and surfactants in the UF concentrate renders the membrane processes unable to recover all of the active ingredients in AFFF wastewater.

Table 3
Membrane Rejection of Reverse Osmosis Process in
Treating the UF Permeate Run at 50°C

Parameter	% Rejection
Glycol	99.65
Surfactants (by Shake Test)	100
TOC	99.7
Conductivity (TDS)	99.25
COD	99.8
COD/TOC	
RO permeate	2.2-3.18
RO concentrate	3.07-3.21

MEMBRANE TREATMENT SYSTEM

Based on an economical analysis, membrane treatment system appears to be the most cost-effective process studied. The RO concentrate has a high potential of being used to supplement the AFFF concentrate which has a current market value of about $12/gallon. A proposed membrane treatment system is depicted in Figure 12, and the cost estimate is shown in Table 4. The RO permeate can also be reused during firefighting exercises.

Table 4
Estimated Capital and Operating Costs of
the Proposed Membrane Treatment System (Fig. 12)
Basis: 50,000 gpd, 300 days/yr

Capital Costs	
Storage Tank, 5000 gal	$ 3,000
Ultrafiltration, 2500 ft^2 @ $30/$ft^2$	75,000
Reverse Osmosis @ $1.0/gal/day	50,000
Drying Lagoon	6,000
Pipings	2,500
Engineering Fee	10,000
Subtotal A	$146,500
Contingencies, 20% of Subtotal A	29,300
	$175,800
Operating Costs	
Electricity (30 H.P.) @ $.03/KWH	$ 4,800
Chemicals	
Cleaning compounds	300
Labor (Avg 2 hr/day) @ $7/hr + 40% OH	6,000
Maintenance, 3% of Capital Costs	5,300
Interest, 4% of Capital Costs	7,100
Taxes and Insurances, 2% of Capital Costs	3,600
Membrane Replacement (20% of Modules)	12,500
Depreciation (10-yr Straight Line on Capital Costs Less Modules	11,400
	$ 51,000

Treatment Costs (O&M)

$$\frac{51,000}{50,000 \times 300} = \$0.00345/\text{gal}$$

$$= \$3.45/1000 \text{ gal}$$

$$= \$0.91/m^3$$

$$= \$2.60/100 \text{ ft}^3$$

Make-up water charge varies from $0.2-1.1/100 ft^3 depending upon locations

ELECTROCHEMICAL ORGANIC CONTENT ANALYZER

The Electrochemical Organic Content (EOC) Analyzer currently being developed by Life Systems, Inc. (LSI), Cleveland, OH was evaluated for its applicability in monitoring AFFF concentration in an aqueous solution.

Experimental results indicate that the EOC Analyzer is more selective for AFFF than a general organic analysis technique such as TOC measurement. The measurement of AFFF concentration in an aqueous solution can have detection sensitivity up to 0.5 ppm (v/v). Wastewater containing high chloride concentration e.g. 200 ppm, could produce small errors to AFFF measurements, respectively 0.6 ppm (v/v) for FC-206 or 6.5 ppm (v/v) for ANSUL. The EOC Analyzer is anticipated to be developed for the use in automated operational control of AFFF treatment process and to monitor process effluent quality.

CONCLUSIONS

The following conclusions may be drawn from this study for the development of a cost-effective treatment and disposal method for the AFFF-laden wastewater.

1. Wastewater containing AFFF resulted from firefighting exercise can effectively be treated by oil-water separation, followed by clarification with or without chemical coagulation, and carbon adsorption or membrane treatment process.

2. Ozonation is the most expenisve process followed by carbon adsorption and membrane process. Carbon appears to have limited capacity, 0.1 gTOC/g carbon observed during carbon column experiment.

3. Membrane process appears to be the most cost-effective process. Part or all of the membrane process O&M cost may be recovered from reuse of reclaimed AFFF and effluent water. This will also meet the 1977 Clean Water Act (PL95-217) guideline, that reuse must be considered as an alternative in new construction of treatment plants. Additional membrane process development work is planned to define the membrane fouling characteristics and to determine applicability of reclaimed AFFF.

4. EOC Analyzer may be employed for automated operational control of AFFF-laden wastewater treatment system and to monitor process effluent quality.

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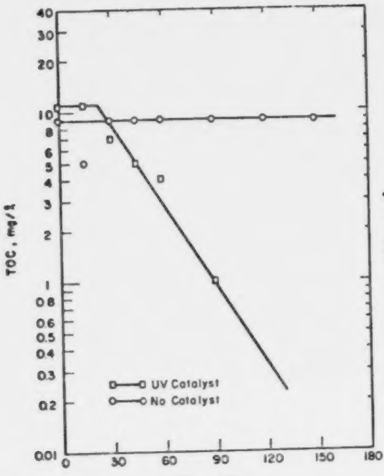

FIGURE 1 FC-206 RO PERMEAT OZONATION

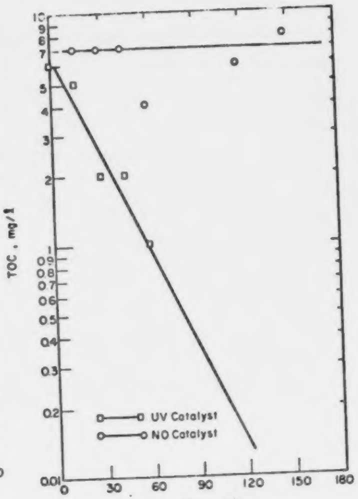

FIGURE 2 ANSUL RO PERMEAT OZONATION

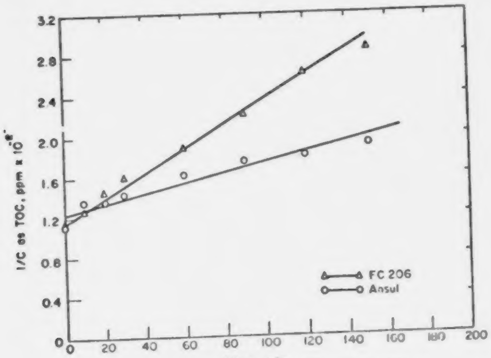

FIGURE 3. KINETIC STUDY OF [illegible] ADSORPTION WITH 14X40 FILTRASORB 400

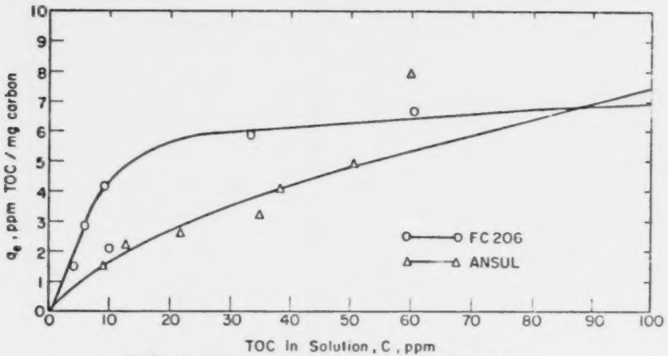

FIGURE 4. ISOTHERM OF AFFF ADSORPTION WITH 14X40 FILTRASORB 400

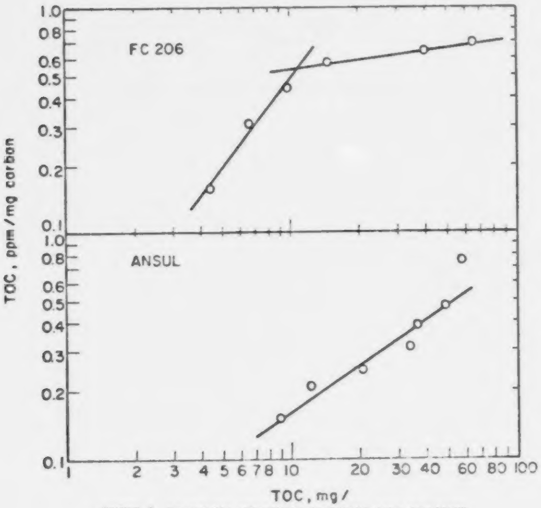

FIGURE 5. FREUNDLICH ADSORPTION ISOTHERMS AFFF SOLUTIONS

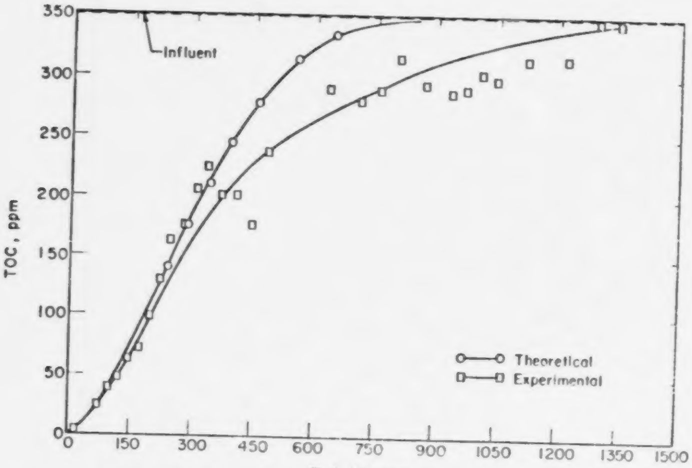

FIGURE 6. COLUMN STUDY OF ANSUL ADSORPTION WITH 14X40 FILTRASORB 400

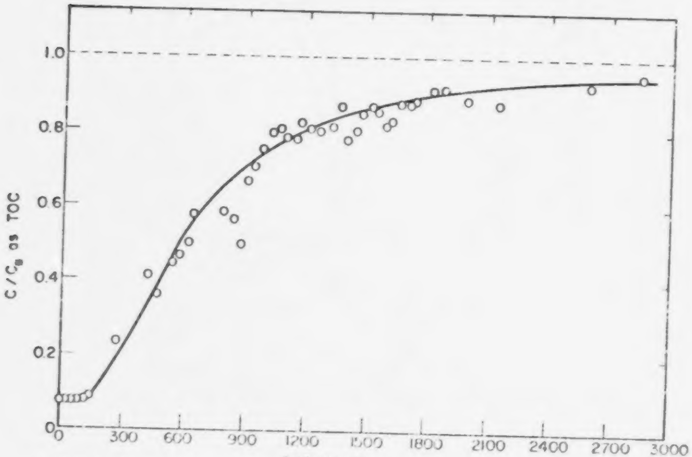

FIGURE 7. FILTRATION AND [illegible] FROM
STUDY OF [illegible] WASTEWATER

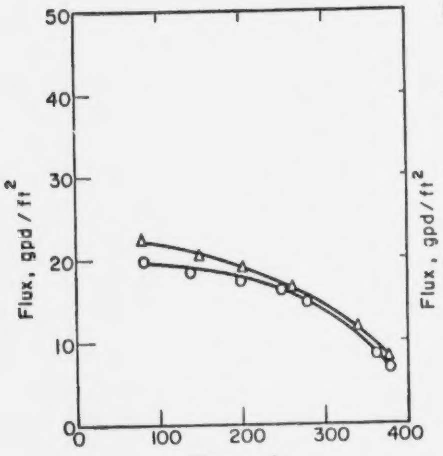

FIGURE 8. ULTRAFILTRATION PROCESS OF DIRECT DISCHARGE WASTEWATER AT 25°C

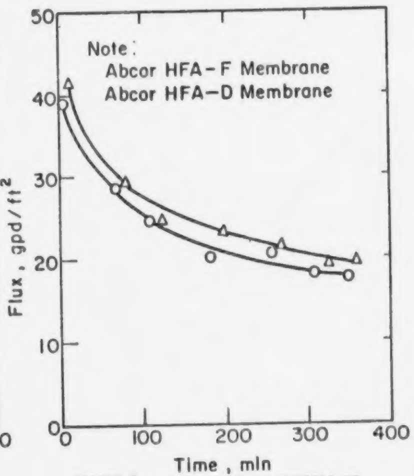

FIGURE 9. ULTRAFILTRATION PROCESS OF DIRECT DISCHARGE WASTEWATER AT 50°C

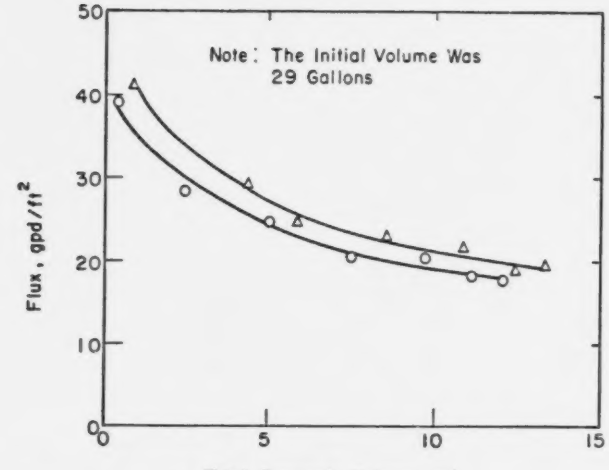

FIGURE 10. ULTRAFILTRATION PROCESS WITH DIRECT DISCHARGE WASTEWATER AT 50°C

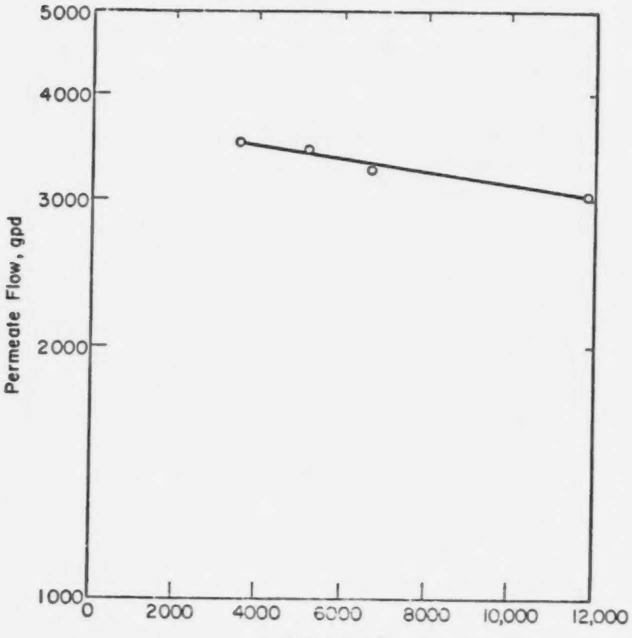

FIGURE 11. RO PERMEATE FLOW VS. TOC

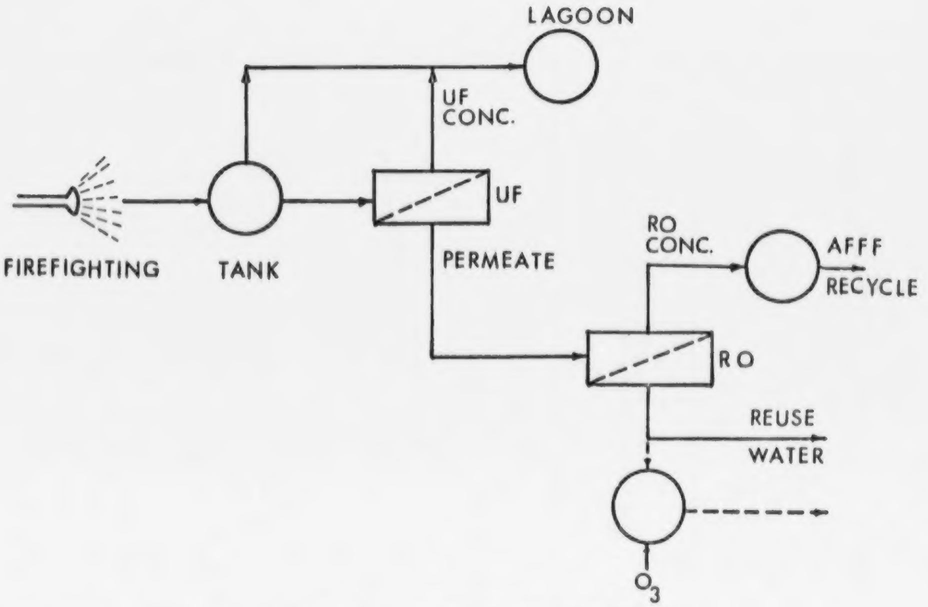

FIGURE 12. PROPOSED MEMBRANE TREATMENT SYSTEM FOR AFFF WASTEWATER

REUSE OF WASTEWATER CONTAINING FIREFIGHTING AGENT
CEL

COAL GASIFICATION WASTEWATER REUSE

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INTRODUCTION

The threatened depletion of world wide crude oil and natural gas reserves has led to the development of technologies capable of providing substitute fuels from alternate fossil energy sources. Abundant coal reserves in the United States have motivated the development of a variety of coal conversion technologies which convert coal into more readily consumable fuels. One such technology is that of high-BTU coal gasification, which typically uses steam and oxygen to convert coal into a methane rich fuel gas. As shown in Figure 1, the high-BTU coal gasification process consists of five main process units. Coal is first contacted with steam and oxygen at high temperature and pressure and is gasified. Gasification reactions produce a raw product gas consisting primarily of H_2, CO, CO_2, and CH_4, in addition to smaller amounts of environmentally significant gases, e.g., H_2S, HCN, and NH_3 and other contaminants. The raw product gas is cooled by direct contact water cooling, and is then passed over a catalyst to promote the CO shift reaction:

$$CO + H_2O \rightleftharpoons H_2 + CO_2.$$

This reaction provides a 3:1 molar ratio of H_2:CO, which is necessary for optimal performance of the downstream methanation reaction.* After cooling, the shifted gas is purified primarily to remove acid gases, via., CO_2 and H_2S. Finally, the clean gas is passed over a second catalyst to promote the methanation reaction:

$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O.$$

The overall process results in a pipeline quality gas with a methane content typically greater than ninety percent.

Water plays an intergral role in the gasification process. Process water inputs include steam to the gasifier, steam or water to the CO shift reactor, water for direct contact gas cooling, and recycle slag/ash slurry water. Process outputs include foul condensates from the gas quench and CO shift systems, a clean condensate from the methanation system, and solids slurries consisting of ash and/or slag from the gasifier and of ash and/or char from the gas quench system. The gas quench and CO shift condensates are typically highly contaminated while the methanation condensate is relatively clean.

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*In the CO_2-Acceptor process, the appropriate H_2:CO ratio is achieved in the gasifier and the shift conversion is not necessary.

Although high-BTU coal gasification appears to be quite attractive in view of abundant coal reserves in the United States, these systems may be limited due to economic, environmental, and other considerations. One important factor which may limit feasibility of gasification involves the availability of another natural resource - water. A coal gasification plant which produces 250 million SCFD of pipeline gas may require anywhere from four to seven million gallons of water per day, (1) depending on the particular process being utilized and on geographical location. Fresh water needs can impose severe limitations on siting a gasification plant, since much of the United States' easily exploitable coal reserves lie in semi-arid regions where municipal, agricultural, and industrial water demands compete for a limited water supply. Even in the Appalachian region, local water shortage may prohibit installation of a large high-BTU gasification facility. For this reason, maximum attention must be given to the design of coal gasification plants in order to ensure that water consumption is minimized. Further, since these processes produce foul condensates which total 50 to 80% of the plant fresh water requirements, treatment of wastewater for complete reuse not only helps make the plants environmentally acceptable but also serves to minimize fresh water needs.

Figure 2 provides a general flow diagram for a coal gasification process water balance which shows the relationship between coal gasification process condensates and other important plant water streams. This figure shows that the exact nature and fate of contaminated wastewater from the gasification process has a significant impact on the overall process water balance. Hence, a thorough understanding of the characteristics of these wastewaters is fundamental to the optimal design of a plant water balance aimed at maximizing wastewater reuse. With knowledge concerning quality, quantity, and treatability characteristics of process wastewaters, and with an understanding of plant water needs and the quality constraints governing these needs, a process engineer can develop several alternate schemes for meeting complete water reuse. Final selection of one specific scheme may then be based primarily on economic factors.

The difficulty involved in applying this engineering evaluation to the design of process water balances for a commercial coal gasification plant arises from the fact that, in general, high-BTU coal gasification water treatment/reuse systems have not been demonstrated at or near commercial scale operation. Therefore, the process engineer must translate wastewater characterization and treatability data generated at bench and/or pilot scale into information which can be accurately applied to the design of a commercial facility.

This paper will outline a general methodology necessary to generate and to translate bench and pilot scale data in order to design a commercial scale plant water balance. Discussion will be applicable to all high-BTU coal gasification systems, and will stress areas in which information and/or knowledge is particularly lacking. Finally, in order to illustrate the application of this methodology to a specific gasification process, a case study using the Hygas process will be presented. Discussion here will focus primarily on the significance of knowledge gained during treatability studies on Hygas pilot plant wastewater, and on the impact of this knowledge on a conceptual commercial plant water balance prepared by Procon, Inc., (2) for the Hygas process.

STRATEGY FOR EVALUATION COAL GASIFICATION PROCESS WATER REUSE OPTIONS

A carefully coordinated assessment strategy must be developed to ensure the generation of appropriate bench and/or pilot scale data which can be used to predict commercial scale water reuse options. The methodology used to obtain these data as well as information necessary to accurately translate these data to a commercial facility includes:

1. Development of a process effluent characterization strategy which will provide environmental data regarding process effluent production characteristics.
2. Evaluation of the effect of process operating conditions and configurations on effluent production, and of other issues influencing the scalability of pilot plant effluent data.
3. Assessment of the strengths and weaknesses of specific candidate treatment systems when applied directly to the treatment of particular process wastewaters, and..
4. An engineering evaluation of quality-quantity constraints governing process water needs, along with an evaluation of specific treatment strategies which are required to meet these needs.

The first point is concerned primarily with developing an overall effluent characterization strategy which will provide an accurate and meaningful representation of process effluent production. The concerns here are that: (1) the most important streams and parameters are being monitored, (2) the most appropriate sampling procedures are employed, and (3) proven preservation and analytical methods, which minimize biases resulting from analytical techniques and/or specie degradation, are used. Specific discussion of these topics have been presented elsewhere, (3) and will not be detailed here. The second point entails an evaluation of the effect of important gasification operating conditions (e.g., gasifier temperature, pressure, and steam/air ratio) and other process operating variables (e.g., physical gasifier configuration, gas residence time, coal heat up rate, and the extent of gas/solids mixing) on process effluent production and effluent distributional trends. In addition to these factors, differences between pilot and commercial scale raw product gas quench systems influence the scalability of pilot plant effluent production data. Comments regarding these topics have also appeared previously, (4,5,6) and will not receive further attention here. It should be noted, however, that these pieces of information are necessary in order to predict commercial scale effluent production characteristics which in turn are used to size and cost treatment systems necessary for meeting wastewater reuse options.

The third and fourth topics are of current interest and comments regarding each issue are discussed below.

Process Wastewater Treatability

A general conclusion from a thorough review of available published literature pertaining to investigations of water management and treatment in coal conversion plants is that the state-of-the-art is not well developed. Extension of this review to include well established related industries, such as byproduct coking, shows that in many respects the data base is still lacking and that answers to important design and operating questions remain largely unknown. For example, contradictory information exists with regard to many basic operating parameters for the biological treatment of ammonical liquors such as dilution requirements, acceptable ammonia levels, and organic loading. It thus becomes apparent that, since transfer of information within an industry is difficult, it is even more difficult to translate this information to a new industry such as coal gasification.(7) Although treatment strategies and operating criteria employed in related industries may provide information regarding the treatment needs of coal gasification wastewater, this information must be proven acceptable by experimentation using actual gasification process wastewater prior to its use for design. Such experimentation could include bench or pilot scale treatment evaluations of selected water treatment systems using specific process wastewaters. However, due to the intermittent and variable operating characteristics of the process pilot plants, the availability of wastewater generally confines treatability studies to the bench scale. A bench scale treatability study is therefore necessary to determine the applicability of selected processes for treatment of gasification wastewaters. With some exceptions, minimum treatment will generally include reduction of organic contamination (e.g., tars and oils, phenol, BOD, and COD) and reduction of ammonia, regardless of the final fate of treated wastewater. Experience gained to date indicates that some gasification systems, e.g., Bigas, CO_2-Acceptor, and Koppers-Totzek, produce relatively little organic contamination. Wastewaters from these processes may therefore not require treatment for reduction of organics. For processes which produce relatively high levels of organics, the most acceptable unit operations necessary to achieve basic treatment include oil/ tar and solids separation, phenol removal, ammonia stripping, and biological oxidation. Treatment of wastewaters by this scheme will usually occur in the sequence mentioned above. High ammonia levels would normally be removed prior to biological treatment since they might otherwise be toxic to microorganisms. If phenol removal is justified, this process would precede ammonia stripping since (1) the acidic character of phenol tends to hold ammonia in solution and thus inhibits the stripping process, and (2) phenol may tend to distill off with ammonia and may thereby interfer with the recovery of ammonia in acceptably pure form for resale.

Phenol removal refers predominantly to removal by solvent extraction, since preliminary evaluations of resin adsorption indicated that regeneration requirements would yield this treatment technically infeasible. Solvent extraction and biological oxidation collectively reduce high levels of phenolics. However, the motivation for solvent extraction is strongly dependent on the extent and nature of phenolics and other organics found in a particular process wastewater. High levels of phenol may lead to several economic incentives for its recovery; not only does removal of high levels of phenol reduce the loading to the biological oxidation system, which consequently reduces both operating and capital costs involved in biological treatment, but recovered phenol can be either sold as a chemical commodity or used as a fuel. Lower phenol levels lead to a correspondingly low incentive for recovery, thus motivating phenol removal entirely by consumption during biological oxidation. However, other factors may influence the need for solvent extraction. For example, a wastewater containing toxic organics and low overall loadings of phenol may require processing by solvent extraction in order to remove the toxic organic constituents. Solvent extraction also helps to protect a biological oxidation facility from shock organic loads. Further, whether or not solvent extraction has preceded ammonia stripping may have a significant impact on the difficult involved in stripping ammonia. It is therefore important to consider all factors effected by solvent extraction, as well as to consider the levels of phenol anticipated in the process wastewaters, in order to improve understanding of the necessity and economic motivations for phenol removal in a commercial facility.

Additional wastewater treatment processes may be necessary depending on the specific fate of the treated water. For example, a different degree of treatment may be necessary to meet quality constraints for cooling water makeup than would be necessary for augmenting boiler feed water needs. In general, such additional treatment is aimed at reducing levels of residual organics and dissolved solids. Candidate treatment schemes to meet these needs include activated carbon adsorption, lime softening, ion exchange, reverse osmosis, and evaporation -- all of which, with the exception of lime softening, are high capital/high operating cost technologies. Bench scale testing of these systems is required in order to determine which specific system or combination of systems is most applicable to achieve a given final water quality.

Wastewater Reuse Options

Treated wastewater may either be recycled directly back to the coal gasification process or may be used to help satisfy other plant water* needs. It is important to recognize that treated wastewaters may contain trace levels of toxic and/or hazardous materials, and emissions of these materials may be better controlled by not mixing treated gasification wastewaters with other plant waters. On this basis, the first priority for reuse of treated wastewater is directly back into the gasification process, with lower priority going for reuse to meet other plant needs. This same priority results from considerations regarding the extent of treatment necessary to meet a given quality constraint, since reuse directly back into the gasification process may require less treatment than that necessary to meet other plant needs.

Specific gasification process reuse choices include: (1) water for coal slurry feeding, (2) water for steam to the gasifier, (3) recycle slurry water for gasifier slag, ash, and/or char removal, (4) direct contact gas quench water, and (5) water for steam to the CO shift reactor. For each of these choices, the extent to which organic and inorganic constituents must be removed is not entirely known. Depending on the manner in which steam is generated to meet either gasifier or CO shift reactor steam needs, it may be sufficient to use water of much lower quality than that normally used in boiler operation. For example, a design of Synthane process (8) uses steam generated in the slag quench zone below the gasifier to partially provide for water needs of the CO shift reaction. Similarly, direct contact gas quench water need only be treated to a quality necessary to maintain its ability to act as a scrubber for water soluble effluents such as ammonia. Since slurry waters are used only to transport slag, ash, and/or char, these waters require little to no treatment and may be reused after solids separation.

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*In the following text, distinction is made between gasification process waters and other plant waters. Gasification process water (e.g., steam to the gasifier) signify those waters which have come into direct contact with either coal or the product gas during processing. Other plant waters (e.g., steam for turbine driving) represent those remaining plant streams which do not directly contact the goal or product gas.

Other plant water needs which may be partially or completely satisfied by using treated wastewater include: (1) cooling water makeup, (2) boiler feed water makeup, and (3) water for solids disposal. Assuming that the degree of reuse of minimally treated wastewater directly back into the gasification process has been maximized, excess wastewater will require treatment to meet quality constraints governing one or more of the above plant needs in order to achieve complete reuse. Since cooling water quality constraints are significantly less demanding than those of boiler feed water, it is most likely that wastewater which is not completely used directly in the gasification process will be used primarily as makeup to the cooling tower. Constraints governing the use of treated water as makeup to the cooling tower reflect the need to control chemical scaling and fouling, biological activity, and corrosion. Therefore, wastewater treated through biological oxidation will probably require some treatment for softening and for reduction of residual organics and BOD. Although the operating quality limitations for cooling water with regard to species which cause fouling and scaling problems can be predicted using equilibria relationships, little can be said *a priori* regarding constraints on species which may promote biological activity (viz, phenol and BOD) and toxic/hazardous materials which may result in emissions via air stripping and/or drift losses.

HYGAS WASTEWATER TREATABILITY CHARACTERISTICS

Evaluation of Hygas wastewater treatability characteristics will draw on experience gained from bench scale treatment of pilot plant liquid effluents. One study by Luthy and Tallon (7) involved a thorough evaluation of biological treatment of a blend of pilot plant wastewaters. Subsequent screening studies using pilot plant quench condensate have focused on the evaluation of a complete treatment train capable of providing various wastewater reuse qualities. Results and design considerations of these studies will be summarized below. A more detailed description of experimental procedures and results will be published at a later date.

Design of a Bench Scale Treatability Study

Figure 3 shows an effluent flow diagram of the Hygas pilot plant. Comparison of these process flow patterns with those of the conceptual

that of the nine pilot plant wastewater streams, five are suitable for scalable plant characterization: agglomerating coal pretreater quench water, gasifier ash slurry water, product gas cyclone slurry water, product gas quench condensate, and oil/water/solids interface blowdown. Experience gained in working with these wastewaters indicate that the cyclone slurry water and the gas quench condensate contain the bulk of liquid effluents produced during gasification. Similarly, comparison of Figures 3 and 4 suggest that the quench condensate in the commercial design should contain the bulk of process liquid effluents.* For this reason, subsequent treatability studies have focused on these effluent streams.

Since July, 1975, several sampling efforts have resulted in various amounts of environmental characterization data for these wastewaters. (3,9) Table I shows results of three sampling efforts, and presents ranges for important effluent constituents in these streams. These data are presented only to provide concentration ranges for effluents in the respective water streams, and are not meant to reflect results of a thorough characterization of Hygas wastewaters. Data presented in Table I may therefore, be in error of effluent production levels anticipated during true steady state operation. It is these data, however, which were used to evaluate a set of necessary treatment systems for bench scale testing of a blend of cyclone and quench condensates (10) and quench condensate without blending.(11) With reference to treatment systems mentioned earlier, the scheme chosen for treatment of Hygas quench condensate is shown in Figure 5. This treatment scheme includes solvent extraction, ammonia stripping, and biological oxidation -- the same sequential treatment scheme which has been incorporated in the Procon commercial concept design.(2)

Although this treatment may be necessary regardless of the ultimate fate of treated water, the extent and nature of further treatment following biological oxidation depends on specific reuse choices. In order to evaluate the most likely necessary additional treatment, the commercial concept design was reviewed. This design incorporated the reuse of biologically treated wastewater as makeup to the process raw water storage pond.** Water from the storage pond was then used as makeup to the boiler feed water, cooling water, and process water systems after appropriate treatment. On this basis, the biological oxidation effluent would require upgrading to a quality approximating that of surface water. Parameters of particular concern included total organic carbon (TOC), total dissolved solids (TDS), calcium, magnesium, ammonia, cyanides, sulfates, and chlorides. Three treatment processes-- activated carbon adsorption, ion exchange, and reverse osmosis -- were selected for evaluation to achieve reduction of residual organics and dissolved solids. These systems were selected with regard to the following considerations: (1) previously established effluent quality requirements, (2) a gross estimate of the costs involved for alternative technologies, and (3) feasibility of evaluation by bench scale testing.

Treatability Characteristics of Hygas Pilot Plant Wastewater

Preliminary screening studies have successfully demonstrated the basic treatability of Hygas pilot plant wastewaters. Results from these studies have served to provide several qualitative conclusions as well as to indicate several areas requiring further investigation.

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* The low temperature to which raw product gas must be cooled during quenching in order to recover slurry oil results in nearly complete water vapor removal. As a result, the bulk of liquid effluents produced during gasification should be contained in the quench condensate.

**Suggested revisions to the commercial concept design call for impoundment of biologically treated effluent separate from raw water storage.

Solvent Extraction. Solvent extraction has been evaluated by batch shake tests using a variety of fresh solvents. As a result of these studies, phenol removal appears to be technically feasible but economically questionable.

A brief economic break-point study has been completed for phenol removal which compares the costs of recovering phenol as a fuel versus the increased cost of removing phenol by biological oxidation. Based on this analysis, phenol recovery can be economically justified for phenol concentrations in the range of 4500 to 6500 mg/l depending on the acceptable loading (i.e., mg COD/mg MLVSS-day) to the biological reactor. This range is conservative, since the value of phenol was based on heat content rather than its value as a chemical commodity. However, in view of the phenol levels in Hygas pilot plant quench condensate, it appears that phenol recovery cannot be justified on an economic basis alone.

Several factors may alter economic considerations governing solvent extraction. First, no evaluation of solvent regeneration or solvent recovery has been made. However, an actual commercial process would require regeneration and recycle of solvent. The ability to separate organics from treated wastewater may have a large impact on the feasibility of the overall process. Thus, an evaluation of the complete solvent extraction process precludes any meaningful economic conclusions. Second, phenol levels in process wastewater are strongly influenced by changes in plant operation. On this basis, differences between proposed commercial and pilot plant operating characteristics have several implications on phenol levels anticipated in commercial plant wastewater. Data reported by Fillo (4) and Nakles, et al, (5) suggest that phenol decomposition will be enhanced in the commercial process. Thus, phenol production may be less than observed in the pilot plant. On the other hand, differences in the volume of quench condensate relative to coal feed rate for the pilot and commercial plants suggest an increase in overall concentrations of phenol, assuming equal phenol production per ton of coal consumed.

Final decisions concerning phenol recovery may be made only after completion of a careful evaluation of anticipated phenol production and distributional trends in the commercial plant. Whether phenol recovery is ultimately ruled out may not depend entirely on economic considerations, but may be influenced by several factors, including the need to remove specific toxic-hazardous organics.

Ammonia Stripping. Little difficulty has been experienced during bench scale NH_3 removal by batch-mode heating and air stripping. Three questions which should be addressed in future research activities are: (1) the disposition of specific chemical species during the stripping process, (2) the effect of choice of chemical used for pH control on downstream biological oxidation and other treatment processes or reuse systems, and (3) the influence of prior treatment by solvent extraction on ammonia stripping.

The fate of H_2S and HCN, in addition to that of NH_3 and CO_2, must be evaluated since the extent of observed removal influences by-product ammonia recovery and dictates necessary cross linkages to gas separation and cleanup facilities. The choice of lime or caustic for raising pH in order to initiate fixed leg stripping entails an analysis of chemical costs, equipment fouling, separation of precipitates, and effect on wastewater dissolved solids. Although a large fraction of ammonia present in this wastewater can be stripped during the free leg cycle of ammonia stripping (~95%), the high ammonia levels in this water result in a significant amount of fixed ammonia remaining to be stripped. If lime is used to raise pH, residual calcium levels can be as high as 650 mg/ℓ and may have significant impact on the ultimate treatment necessary to meet reuse needs.

Two evaluations of ammonia stripping have been completed in which prior treatment of raw quench wastewater by solvent extraction had not been performed. These evaluations suggested that wastewater phenol levels may have a significant effect on ammonia stripping, since the presence of high phenol levels appeared to lower the rate of ammonia removal during laboratory bench scale stripping operations.

Biological Oxidation. As a result of studies with Run 72 quench water and with Run 64 quench and cyclone slurry condensates, (7) considerable experience has been gained with basic biological treatment of Hygas effluents. Nonetheless, several issues remain unanswered. One of the most critical issues is the fate of trace organic compounds through biological treatment. Composite samples have been collected and prepared for preliminary trace organic characterization. These data should provide some qualitative understanding of removal efficiencies. Further work will be needed to confirm these results and to determine how system operating variables relate to removal of trace organics. The extent to which biological sludge has transformed, rather than merely adsorbed, trace organic compounds also requires evaluation.

Demineralization. Preliminary studies aimed at evaluating demineralization by ion exchange and by reverse osmosis have been completed. Bench scale testing of cation and anion exchange columns indicated that very good breakthrough characteristics could be obtained during treatment of biological effluent. Bed capacities in the range quoted by resin manufacturers were obtained during treatment of wastewater which had been pretreated by activated carbon adsorption. Treatment of wastewater which had not received similar pretreatment resulted in approximately 30% reduction in bed capacity.

Evaluations of reverse osmosis indicated that a clear, colorless permeate could be obtained by treatment of biological reactor effluent. However, several problems were encountered. Operation may be limited to about 50% recovery due to problems with calcium sulfate precipitation. In addition, membrane rejection characteristics appeared to deteriorate over a short (two week) period of time.

Residual Organic Removal. Bench scale evaluations of carbon adsorption by batch shake tests and by continuous flow column operation have been completed. These systems were monitored for removal of chemical oxygen demand (COD). COD data from batch shake tests were successfully fitted to the Freundlich adsorption model, producing straight line isotherms over the entire range of equilibrium COD levels obtained. However, column operation could achieve at best 75% removal of influent COD. Corresponding visual observations concerning color removal suggested restricted capabilities of carbon column treatment.

EVALUATION OF HYGAS PROCESS WASTEWATER REUSE OPTIONS

In light of preliminary treatability evaluations of Hygas pilot plant wastewater, several comments can be made concerning factors which influence the reuse of this wastewater. Discussion here will be aided by first considering the relationship between gasification process and plant water needs and process wastewater in the plant water balance.

The Hygas commercial plant water balance (2) is shown in Figure 6.* Water needs associated directly with the gasification process include high pressure (1450 psig) steam and ash quench slurry water to the gasifier, char slurry water to the gas quench, high pressure steam to the hydrolysis, shift, and methanation unit, and steam to the oil purification system. Other plant water needs include makeup to the boiler feed water and cooling water systems, and process water for various uses including chemical dilution, washdowns, makeup to the flue gas cleaning system, makeup to the acid gas removal system, and makeup to solid waste treatment system.

As noted earlier, foul quench condensate is treated by solvent extraction for phenol recovery, ammonia stripping, and biological oxidation. The bulk of the treated water is then returned to the plant holding pond, and receives further treatment as necessary depending on whether the water is used as high or low pressure boiler feed water makeup or as cooling tower makeup. Some treated water is sent to the solids dewatering and disposal system, and is ultimately used as recycle gasifier ash slurry water.

Unlike other gasification process designs, (11,12) the conceptual Hygas plant considered here does not include production of a separate CO shift condensate. This condensate would otherwise have a quality comparable to the quench condensate, and would therefore require similar treatment. Further, when processing occurs by discrete units as shown in Figure 1, the methanation condensate is anticipated to be of sufficient quality to choose reuse as makeup to the plant boiler feed water preparation system over reuse as makeup to the cooling water system. These differences result from the inherent processing configuration of the proprietary hydrolysis, shift, and methanation unit, which produces one liquid effluent stream (referred to as methanation condensate in Figure 6) consisting of a mixture of methanation and CO shift condensates. The quality of the resulting liquid effluent should be sufficient for reuse directly in the plant cooling tower without further upgrading. Another important difference from other designs is that water needs of the CO shift reaction are supplied primarily by the internal configuration of this unit. Consequently, the shift reactor does not require an input of excess water or steam from either the plant process water or steam systems as is the case in other Hygas plant designs. (11, 12)

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*Flow rates for streams in Figure 6 are provided to give some sense for the relative magnitudes of these streams. Some values are not necessarily precisely defined by plant design constraints, and thus have been adjusted where necessary to complete a balance.

In an actual commercial plant, it is doubtful that biologically treated water would be mixed with raw makeup water to supply plant water needs. In many respects, treated wastewater will be of much lower quality than the raw makeup water, and mixing the two streams results in a larger volume of lower quality water. In addition, treated water will inevitably contain dissolved solids and residual organics specific to the gasification process and not normally found at significant levels in the raw makeup water. For example, treated wastewater may contain dissolved solids (e.g., S^{2-}, CN^-, and SCN^-), organics (e.g., phenolics, and other BOD and/or COD material), and toxic/hazardous metals or organics at levels much higher than would be expected in raw makeup water. For these reasons, treated water should be processed directly for reuse or should be stored in a separate holding pond.

Given the choice of treating the process water for use as makeup to the boiler feed water system or as makeup to the cooling water system, the less rigid constraints governing cooling tower operation indicate that use for cooling tower makeup would be more attractive. Additional treatment in this case would include both residual organic removal and demineralization, aimed primarily at enhancing tower operation by reducing levels of constituents which normally limit tower performance (i.e., those constituents which may lead to fouling and scaling, corrosion, and biological activity). Water treated in this fashion,would not only be of sufficient quality for reuse in the cooling tower, but may provide a portion of the makeup water needs to the biological oxidation unit shown in Figure 6. However, treatment to meet only cooling tower operational guidelines may not be sufficient to satisfy environmental emission criteria. If toxic and/or hazardous materials, such as trace metals and trace organics, are not completely removed through treatment, cooling tower drift and evaporation losses may result in emissions of any toxic or hazardous materials found in the circulating water. Consequently, additional treatment would be necessary to remove these trace contaminants from wastewater prior to use as cooling water makeup. As a result, it may no longer be prudent to use this water as cooling water makeup, since the subsequent quality of such an extensively treated water may approach that necessary for boiler feed water. In this case, it may be more economical to use treated wastewater as makeup to the boiler feed water makup system, and use raw water as makeup to the cooling tower. From Figure 6, either of these alternatives is within the constraints imposed by respective water quantity needs.

It is recognized that net fresh water consumption (15.1 million gallons per day (MGD) for the design in Figure 6 is approximately two to four times higher than estimates of 4-7 MGD (1) for facilities of comparable production. Although the 15.1 MGD value is within 15% of the anticipated water consumption for another Hygas plant design utilizing eastern coal, (12) both values differ significantly from the range of 4-7 MGD. Reasons for this discrepancy are not clear at this time, but may be related to differences in critical design assumptions and constraints. Important factors which may influence this discrepancy include: (1) overall process conversion efficiency, (2) the degree of dry versus wet cooling, (3) heat load dissipated in the cooling tower per pound of water evaporated, and (4) the cooling range of the circulating water. Items two through four above may account for most of the difference, since evaporation losses account for nearly 70% of the net plant water consumption. For example, Probstein and Gold suggest a heat load dissipation rate of 1400 BTU per pound evaporated, (1) while Procon, Inc., (2) has assumed a value of 1000 BTU per pound. This factor alone may account for as much as 30% of the discrepancy noted above. Issues such as these should be clearly evaluated before potentially inaccurate conclusions regarding plant water requirements are made.

CONCLUSIONS

The ability to achieve complete reuse of wastewaters from the coal gasification process may have a significant impact on the feasibility of a commercial scale high-BTU coal gasification plant. However, since little to no treatment and/or reuse data for a commercial plant have been generated to date, treatment and reuse options for a given gasification process are not well understood. Important knowledge regarding the design of a commercial water balance must therefore be based on experience gained at the bench and/or pilot scale. In order to ensure the generation of appropriate bench/pilot data which can be used to design a commercial plant water balance, a carefully coordinated testing program must be developed. Two important areas of this testing program include: (1) an evaluation of process wastewater treatability characteristics using selected treatment systems, and (2) an evaluation of plant water reuse options as governed by quantity and quality constraints governing plant water needs.

In view of preliminary observations, the concept of complete wastewater reuse appears feasible for high BTU-coal gasification facilities. Several reuse alternatives exist, and the extent and nature of treatment necessary to achieve reuse depends on the ultimate fate of treated wastewater. Little to no treatment may be necessary for reuse directly back to the gasification process, while more extensive treatment is necessary to meet other plant needs.

For the particular case of the Hygas process, nearly all process wastewater will be treated as necessary for reuse as makeup to the plant cooling tower. Treatment by ammonia stripping and biological oxidation appears to be fundamental to reduce high loadings of ammonia and organics, while some extent of demineralization and residual organic removal will be necessary to achieve a water quality within the constraints governing cooling tower makeup water. The issue regarding the need for solvent extraction is based largely on economics, and it is not clear whether solvent extraction for phenol recovery can be justified on this basis alone. Other important factors which may counter any adverse economic considerations are the need to protect the biological reaction from shock organic loads and the need to remove non-biodegradable trace organic compounds.

Two primary issues remain unanswered with regard to the reuse of Hygas wastewater in the plant cooling tower. First, minimum quality constraints for organic contamination (e.g., phenols, BOD, and COD) are not clearly understood and must be evaluated. Second, the fate of toxic and/or hazardous materials during wastewater treatment and during cooling tower operation must also be assessed. These factors should ultimately determine the most appropriate treatment scheme necessary to achieve complete reuse of wastewater in the cooling tower.

Discrepancies exist with regard to anticipated net fresh water needs of a commercial scale Hygas process. Resolution of this issue requires careful review of critical design assumptions and constraints. This will ensure that accurate estimates of plant water requirements have

have been made, and that these estimates reflect concern for minimizing water consumption.

ACKNOWLEDGEMENTS

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TABLE I. HYGAS PILOT PLANT WASTEWATER CHARACTERISTICS FOR GASIFICATION OF ILLINOIS NO. 6 BITUMINOUS COAL

Parameter*	Hygas Run 54(3)		Hygas Run 70(7)	Hygas Run 72(11)
	Cyclone Slurry	Quench Condensate	1:1 Blend**	Quench Condensate
COD	--	--	3,000-5,100	7,000-14,000
TOC	110-480	820-1,400	--	--
Phenol	220-450	860-1,500	560-900	1,300-2,000
NH_3-N	180-420	4,000-9,400	2,600-4,600	11,000-13,400
NO_3^--N	--	--	1-5	0.02-1.10
Organic-N	--	--	4-10	24-41
P	--	--	0.5-1.8	3-29
CN^-	--	--	0.1-0.7	1-85
SCN^-	10-60	70-170	17-45	6-150
S^{2-}	1-18	430-1,100	60-220	60-560
SO_4^{2-}	--	--	60-180	60-370
Alkalinity, as $CaCO_3$	--	--	9,800-15,000	38,000-45,000
Conductivity, µmhos/cm	--	--	30,000	22,000-46,000
TDS	300-600	830-1,500	--	--
TSS	4,600-12,000	10-150	--	--
pH,Units	8.9-10.1	7.1-9.0	7.8-8.0	7.8-8.4

* All concentrations are in units of mg/l except as noted.

**These analyses are of a 1:1 blend of cyclone slurry and quench condensates.

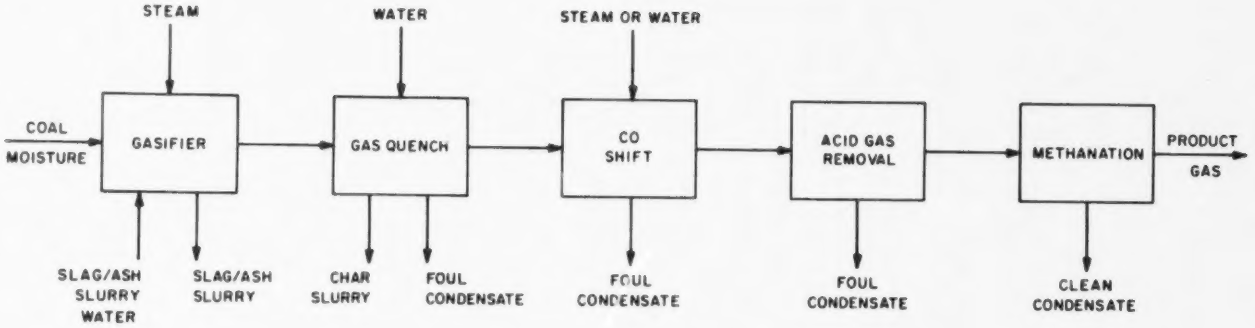


FIGURE 1 BLOCK FLOW DIAGRAM OF MAJOR INFLUENT AND EFFLUENT WATER STREAMS INTERACTING DIRECTLY WITH THE HIGH BTU COAL GASIFICATION PROCESS.

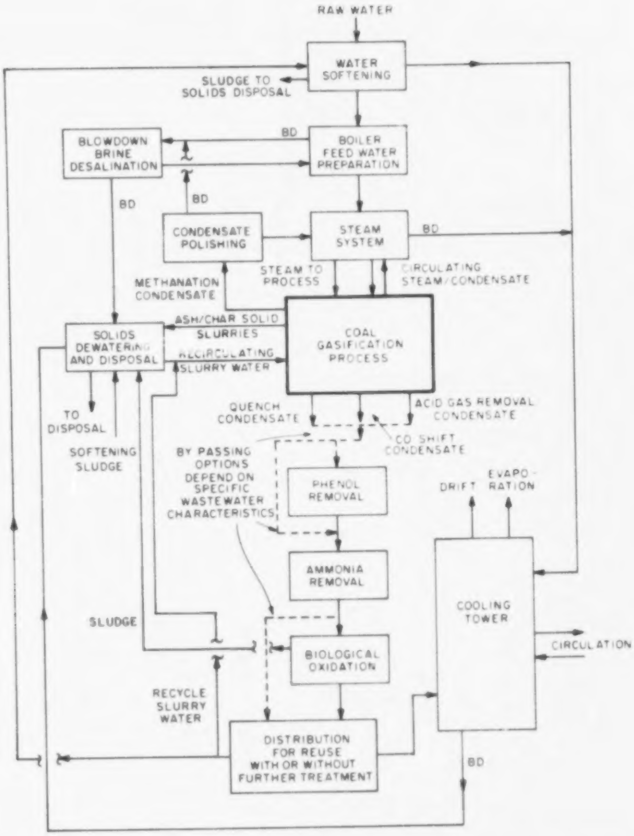

RAW WATER
WATER SOFTENING
SLUDGE TO SOLIDS DISPOSAL
BLOWDOWN BRINE DESALINATION
BD
BOILER FEED WATER PREPARATION
BD
BD
CONDENSATE POLISHING
STEAM SYSTEM
BD
METHANATION CONDENSATE
STEAM TO PROCESS
CIRCULATING STEAM/CONDENSATE
ASH/CHAR SOLID SLURRIES
SOLIDS DEWATERING AND DISPOSAL
RECIRCULATING SLURRY WATER
COAL GASIFICATION PROCESS
TO DISPOSAL
SOFTENING SLUDGE
QUENCH CONDENSATE
ACID GAS REMOVAL CONDENSATE
CO SHIFT CONDENSATE
BY PASSING OPTIONS DEPEND ON SPECIFIC WASTEWATER CHARACTERISTICS
PHENOL REMOVAL
DRIFT
EVAPO-RATION
AMMONIA REMOVAL
COOLING TOWER
SLUDGE
BIOLOGICAL OXIDATION
CIRCULATION
RECYCLE SLURRY WATER
DISTRIBUTION FOR REUSE WITH OR WITHOUT FURTHER TREATMENT
BD

FIGURE 2 SCHEMATIC REPRESENTATION OF MAJOR WATER STREAMS IN A COAL GASIFICATION PROCESS WATER BALANCE.

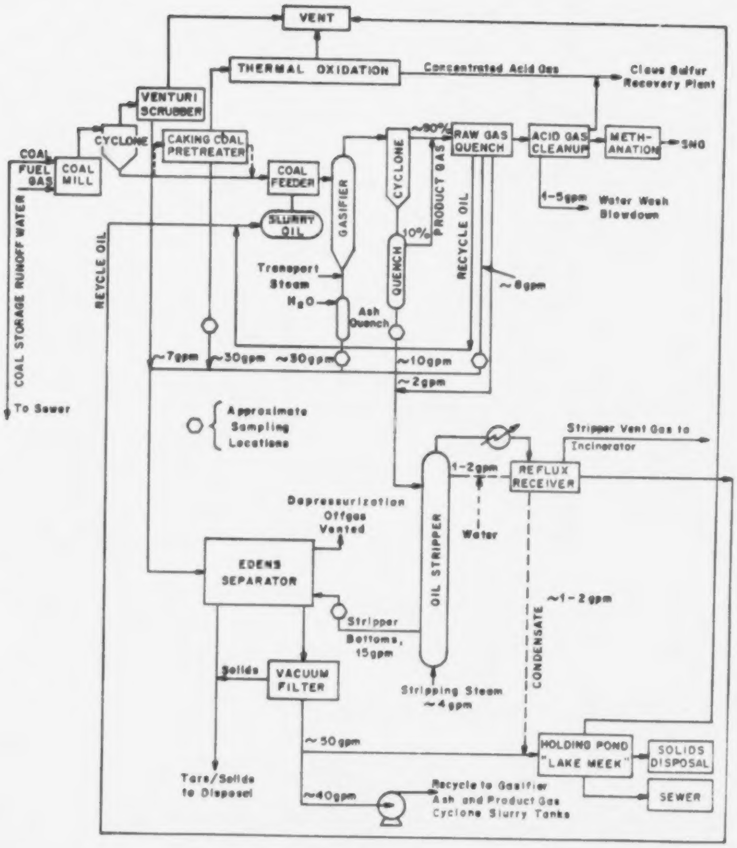


FIGURE 3 EFFLUENT FLOW PATTERNS IN THE HYGAS PILOT PLANT[3].

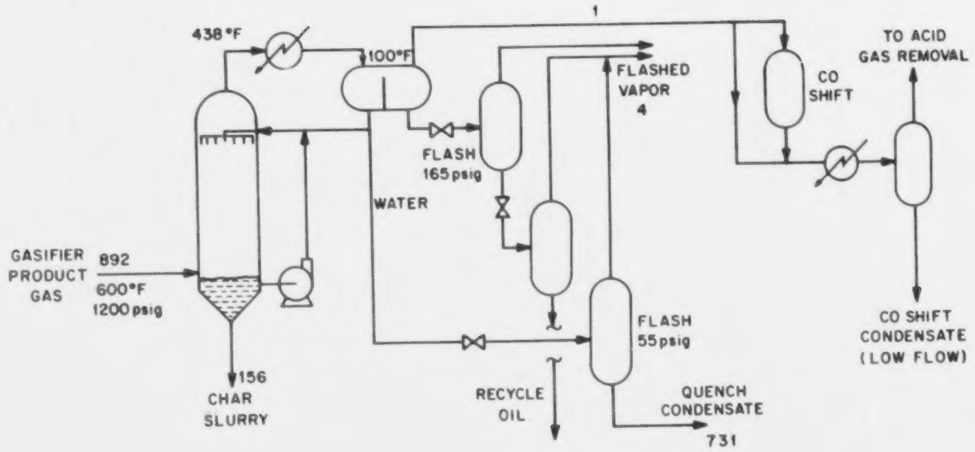


FIGURE 4 CONCEPTUAL COMMERCIAL FLOW DIAGRAM FOR THE HYGAS PROCESS UTILIZING EASTERN COAL[2]. FLOW RATES ARE GIVEN FOR WATER IN UNITS OF 1000 LB/HR BASED ON 250 MSCFD PIPELINE GAS PRODUCED.

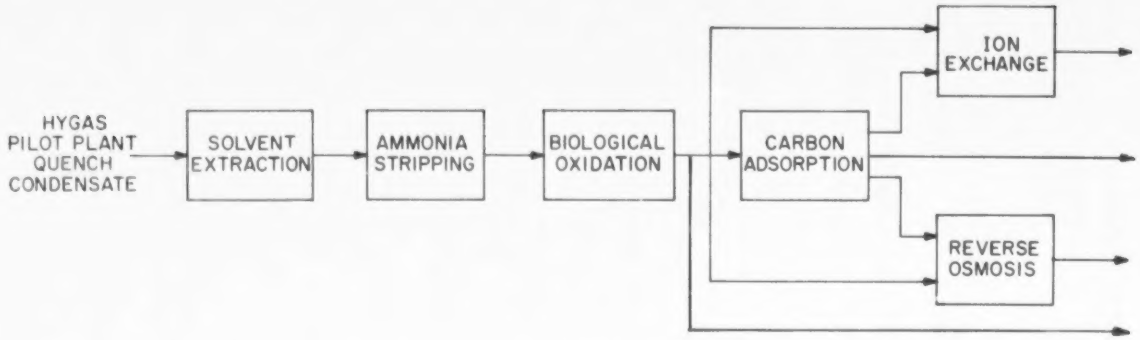


FIGURE 5 BENCH SCALE TREATMENT TRAIN USED TO EVALUATE TREATABILITY CHARACTERISTICS OF HYGAS QUENCH CONDENSATE.

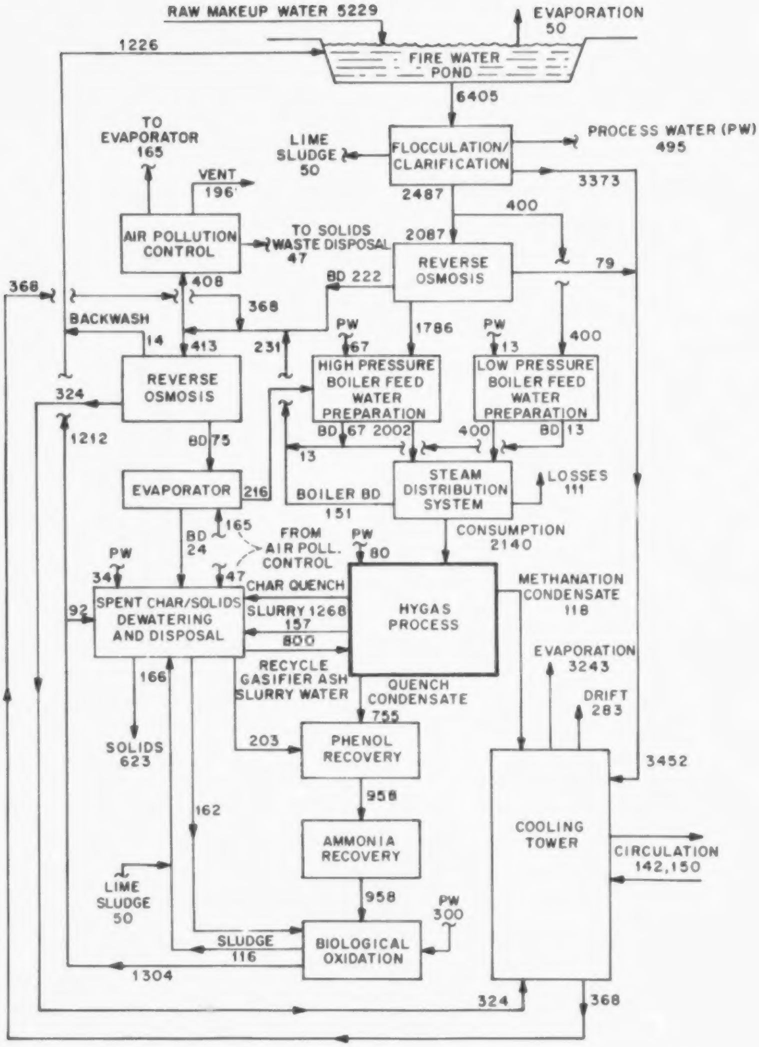
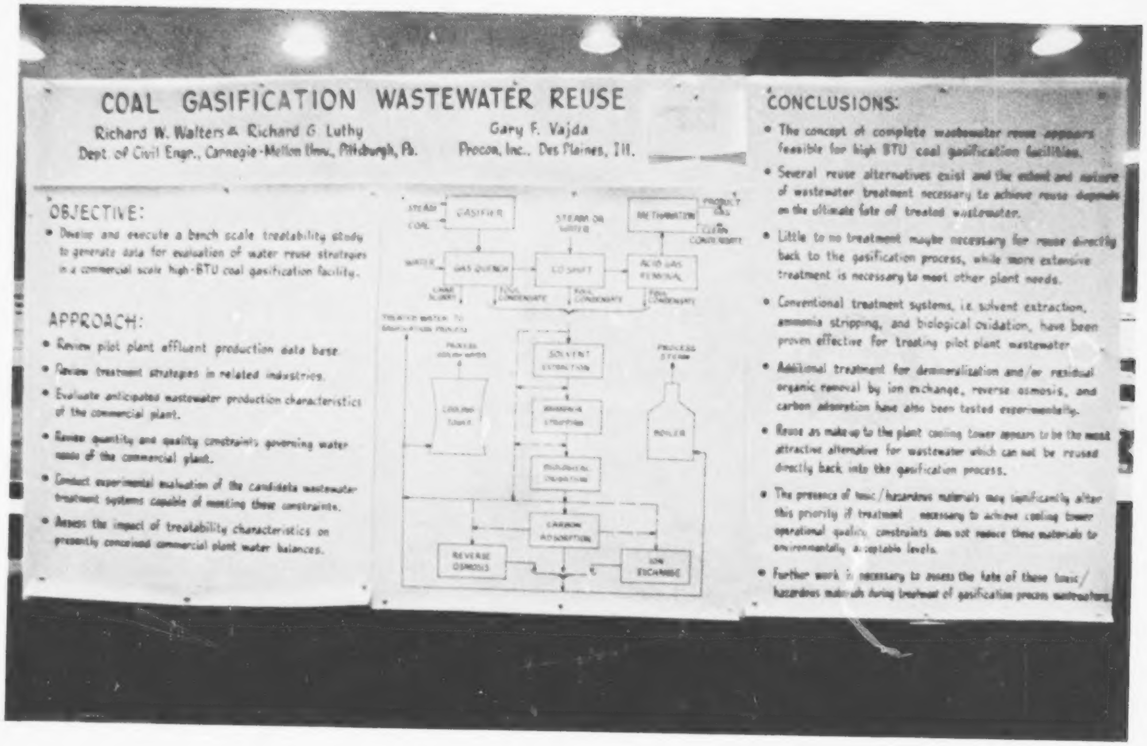


FIGURE 6 CONCEPTUAL COMMERCIAL PLANT WATER BALANCE FOR THE HYGAS PROCESS UTILIZING EASTERN COAL[2]. FLOW RATES ARE GIVEN FOR WATER IN UNITS OF 1000 LB/HR BASED ON 250 MSCFD PIPELINE GAS PRODUCED.



COAL GASIFICATION WASTEWATER REUSE

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OBJECTIVE:

- Develop and execute a bench scale treatability study to generate data for evaluation of water reuse strategies in a commercial scale high-BTU coal gasification facility.

APPROACH:

- Review pilot plant effluent production data base.
- Review treatment strategies in related industries.
- Evaluate anticipated wastewater production characteristics of the commercial plant.
- Review quantity and quality constraints governing water needs of the commercial plant.
- Conduct experimental evaluation of the candidate wastewater treatment systems capable of meeting these constraints.
- Assess the impact of treatability characteristics on presently conceived commercial plant water balances.

CONCLUSIONS:

- The concept of complete wastewater reuse appears feasible for high BTU coal gasification facilities.
- Several reuse alternatives exist and the extent and nature of wastewater treatment necessary to achieve reuse depends on the ultimate fate of treated wastewater.
- Little to no treatment maybe necessary for reuse directly back to the gasification process, while more extensive treatment is necessary to meet other plant needs.
- Conventional treatment systems, i.e. solvent extraction, ammonia stripping, and biological oxidation, have been proven effective for treating pilot plant wastewater.
- Additional treatment for demineralization and/or residual organic removal by ion exchange, reverse osmosis, and carbon adsorption have also been tested experimentally.
- Reuse as make-up to the plant cooling tower appears to be the most attractive alternative for wastewater which can not be reused directly back into the gasification process.
- The presence of toxic/hazardous materials may significantly alter this priority if treatment necessary to achieve cooling tower operational quality constraints does not reduce these materials to environmentally acceptable levels.
- Further work is necessary to assess the fate of these toxic/hazardous materials during treatment of gasification process wastewaters.

PLANNING FOR REUSE

REGIONAL WATER REUSE IN SOUTHERN CALIFORNIA

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INTRODUCTION

Recent developments in water reuse in Southern California may interest those in other regions who are facing any of the following conditions:

- A wastewater sector which is being upgraded to secondary and tertiary treatment to meet legal requirements for stream discharge.
- A water supply sector which is experiencing political and environmental opposition to planned water supply projects.
- A need for practical health standards which can be applied to reuse project planning and design.

Catastrophes are the classic forerunner of positive action in water planning, because in normal years there is little public perception of a problem. In 1977, in the midst of California's latest drought, efforts were intensified to set the house in order---long-delayed elements of the State Water Project were proposed for authorization, plans were put forward to correct groundwater overdrafts in the Central Valley, concepts for conjunctive use of surface water and groundwater storage were revived, and three regional water reclamation studies were established to remove the barriers to expanded water reuse in the State.

This paper presents the background, motivation, and steps being taken by the Orange and Los Angeles Counties Water Reuse Study to expand water reuse in a two-county study area of Southern California (Figure 1). Additional detail is provided in the Study's Phase I Report and Work Plan[8], which is available on request. The Study is undertaking innovative work in three key areas where obstacles to reuse remain: health criteria for certain types of reuse, marketing to determine the actual demand for the product, and project financing as part of State water development.

GENERAL BACKGROUND

Water reclamation in California is a specialized water source which has evolved over a long period of time outside the mainstream of water supply development.

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Fifty years after the first planned reuse projects, the State now has more than 200 reclamation plants serving some 350 reuse sites with a total usage of 184,000 acre-feet per year (AFY). Within Orange and Los Angeles Counties, fourteen reclamation plants serve some fifty reuse sites with a total of 50,000 AFY (Crook & Spath[2]). These amounts represent about 0.5% of the State's applied water usage of 40 million acre-feet per year (MAFY) and about 3% of the two-county water usage of 2 MAFY.

Despite the relatively small quantities, the many years of operating experience with a wide variety of reuse projects has established three essentials for further expansion: (1) a public acceptance of engineered, licensed reuse projects, (2) a tested set of health criteria for most reuse applications, and (3) the demonstration of water reuse as an operational rather than developmental technology. To name only a few of many existing projects, one would include industrial cooling by the Central Contra Costa Water District (Flett[3]), power plant cooling in the cities of Burbank (Woodburn[16]) and Glendale, a sea-water intrusion barrier at the Water Factory 21 site in Fountain Valley in Orange County (Argo[1]), dual systems for suburban landscape irrigation in the City of Irvine (IRWD[4]), a host of landscape and agricultural irrigation sites in the cities of Irvine, Pomona, and elsewhere, groundwater recharge by surface spreading and percolation in the Whittier Narrows area of Los Angeles County (SWRCB, McMichael & McKee[9]), and pasture irrigation throughout the Central Valley and other inland agricultural areas (Crook & Spath[2]).

Prompted by a recent severe drought typical of dry years which reoccur on the average of once in every seven years in California (MWD Rpt. 935[12])--the Orange and Los Angeles Counties Water Reuse Study was initiated in July 1978 under the following favorable circumstances:

1. Large quantities of secondary and tertiary-treated wastewater are now being produced to comply with State and Federal water quality laws of the early 1970's.
2. Predictable health criteria have been established for the design and operation of most types of reuse projects.
3. New water supplies are needed--and development plans are now being formed--at both the State and regional levels.
4. There is a potential complementary relationship between conventional water development and water reuse.

WATER REUSE IN RELATION TO WATER SUPPLY PLANNING

Seventy-five percent of California's water supply originates north of Sacramento, while seventy-five percent of the State's water demand lies south of Sacramento (DWR Bulletin 160-74[10]). The backbone of water development in California is an extensive network of canals and aqueducts developed since the early 1900's to link upland water supplies to urban centers such as San Francisco and Los Angeles, and to the great Central Valley which has become the nation's top cash-producing farmland as a result of imported water. (DWR Bulletin 160-74[10]).

In Southern California, the following three import systems supply two-thirds of the total water demand (Figure 2): the Los Angeles Aqueduct (c. 1913) from the Owens-Mono Basins at the foot of the Sierra Nevada mountain range, the Colorado River Aqueduct (c. 1941) originating at Parker Dam on Lake Havasu between California and Arizona, and the California Aqueduct, or State Water Project (c. 1972) originating in the Sacramento-San Joaquin Delta in Northern California. The potential drainage area which is tributary to Southern California through these aqueducts is more than 100,000 square miles, stretching as far east as the westerly slopes of the Rocky Mountains in Colorado and Wyoming, and as far north as the Klamath Mountains in northern California and southern Oregon.

From very early days, political and growth interests in the origin areas of these supplies--and in downstream areas below the points of diversion--have resisted the Central Valley's and Southern California's legal entitlement to the water. Following a U.S. Supreme Court decision in 1964, and ensuing political compromises, such as completion of the Central Arizona Project and implementation of court-decreed Indian water rights, California's diversion from the Colorado River is being reduced from 1,212,000 AFY to 450,000 AFY, starting in 1985. (MWD Rpt. 935[15]). In northern California, the planned construction of the State Water Project (SWP) has not proceeded beyond the initial reservoirs at Oroville and San Luis. The rated yield of the SWP remains at 2.2 MAFY while construction is ten years behind schedule and slipping further, even though the State is becoming unable to meet its contract commitments. By 1990, the earliest year the SWP could be expanded, entitlements will have reached 4.2 MAFY, while firm yield will remain at about 2.2 MAFY (DWR Bulletin 132-78[14]). Consequently, shortages in normal rain years are anticipated by 1985 as SWP planned deliveries begin to exceed 3 MAFY (MWD Rpt. 935[15]). Figure 3 relates SWP shortage to the water planning situation in the Study Area.

Local water supply planning is now centering on the SWP because other sources, such as local runoff and the Los Angeles Aqueduct, are already fully utilized, and the Colorado River supply is being reduced. The decisive project of the SWP, presently before the State Legislature for authorization, is the Peripheral Canal, a 40-mile long, 400 foot-wide by 30 foot-deep trapezoidal canal which would encircle the Delta. The canal will intercept influent streams for release at a number of optimally located points to improve water quality in the Delta as well as increase the SWP yield by a significant amount. This project is hydraulically essential to protect Delta water quality and to ensure a high-quality water supply within and outside the Delta area. In this latter connection, the Peripheral Canal appears important to Southern California not only as an added water supply, but also to ensure low-TDS water required for expansion of water reuse under a "successive-use" concept.

There has been an unfortunate tendency among both water supply and reclamation professionals to think of water importing and water reuse as opposites. In fact, the two are compatible and each complements the weaknesses of the other. Reuse is a specialized source with many constraints limiting its application, especially for domestic and potable uses, whereas imported water can supply all uses. What is important is that reuse can supply many uses for which imports are not needed, and can save the high marginal cost of importing fresh waters to meet these needs. At the same time, the low TDS of imported waters is essential to the economical successive-use concept of reuse. The overriding weakness of imports is their uncertainty due to political and economic forces which control their scheduling and effectively invalidate historic agreements. Reuse, on the other hand, can be implemented under straightforward local control. As such, water reuse can add a degree of firmness which is inherently missing in imports.

The increasing availability of reclaimed water in the Study Area is beginning to make it more and more attractive as a complement to imports--not so much because of cost factors, but because it's there.

RECLAIMED WATER IS AVAILABLE FOR USE

Considering the authorization by Congress of $28 billion to construct wastewater facilities under P.L. 92-500, it has been said that the nation is beginning to spend as much money getting rid of wastewater as obtaining new fresh water. Since 1970, the three large sanitation authorities serving Orange and Los Angeles Counties have initiated construction of new facilities totaling some $500 million and have committed themselves to O&M costs in the range of $50 million per year in order to meet legally-mandated requirements of P.L. 92-500 and the State's Porter-Cologne Water Quality Control Act of 1969. Figure 4 illustrates the long-term trends towards treatment upgrading in the Study Area. The overall goal of the regional study is to determine how much additional money will have to be spent in order to get these treated wastewaters out of the ocean and into productive use.

An immediate stimulus for reuse is the construction of a number of tertiary treatment plants, which are necessary to meet the State's stringent requirements on wastewaters discharged to inland streams (rather than directly to the ocean). The State requires a virtually virus-free effluent due to recreational use of inland discharges. Furthermore, the State's non-degradation policy for groundwaters may require demineralization or equivalent salt blowdown where the mineral content of wastewaters exceeds that of the underlying groundwaters. In a growing number of cases, it has been found more economical to build advanced treatment plants inland than to construct long coastal interceptor sewers and secondary treatment plants prior to ocean disposal, especially when a second use may be made of the advance-treated wastewater.

Referring to Figure 5, a series of inland tertiary plants have been built or proposed in the Study Area, including the proposed Sepulveda Water Reclamation Plant (WRP), the Los Angeles-Glendale WRP, the Burbank WRP, the Whittier Narrows WRP, the San Jose Creek WRP, the Pomona WRP, the Los Coyotes WRP, the Long Beach WRP, the proposed Anaheim Forebay WRP, and the Michelson WRP (in Irvine, not shown on map). These facilities represent an existing 125,000 AFY of tertiary effluent, with planned expansions and new construction expected to add another 100,000 AFY by the mid-1980s. Each of these facilities is located at elevations which permit low-lift pumping to appropriate use areas or spreading grounds. The typical treatment sequence at these inland facilities includes primary settling, conventional air activated-sludge, secondary settling, chemical injection/rapid mix, direct filtration using inert media or activated carbon, chlorination, and dechlorination, the latter to protect downstream aquatic habitat. Table 1 is a brief summary of plant capacities and typical effluent characteristics at the existing facilities.

Typical plant design criteria are summarized in Table 2, in accordance with State Department of Health criteria for body-contact recreation and spray irrigation forms of water reuse. The activated sludge process is typically designed for hydraulic detention times of 4-8 hours, BOD_5 loadings of 35-45 lb/1,000 cu.ft.-day, and secondary clarifier overflow rates of 700 gpm/ ft^2, and is operated to yield secondary effluent suspended solids of less than 10 mg/l. The DOH filter specifications shown in Table 2 are based largely on comparative testing of alternate filter designs in the Pomona Virus Study (LACSD[6]).

The design and operational criteria in Table 2, have been established by DOH as providing a safe and standard level of virus removal adequate for body contact. It is emphasized that the specifications on Table 2 are supplemented by rigorous reliability criteria to ensure that contingencies can be safely handled, and also by strict cross-connection and backflow prevention requirements which are enforced by county health departments.

RECENT DEVELOPMENTS IN HEALTH CRITERIA

Predictable health criteria are important keys to reuse planning, research, and project implementation in Southern California. The key word is "predictable." The lack of consistency in developing case-by-case criteria makes research aimed at technology improvement difficult and risky, makes project planning almost impossible, and fosters a lack of confidence that any set of permanent or reliable criteria can be reached.

The California Department of Health (DOH) embarked three years ago on a procedure which is conservative, practical, and encouraging of new technology. That procedure is based first on establishing technology standard for a given type of reuse. DOH will support reuse projects which are designed to that standard. However, DOH will permit the demonstration of "equivalent technology" where a project proponent feels that the necessary pilot studies are a good dollar risk. The initial technology standard is not always popular among reuse proponents, and it may be considered to be too stringent and arbitrary. On the other hand, a technology standard provides a practical basis for project planning, as well as a straightforward means for demonstrating equivalent technology by piloting candidate processes in parallel with a standard process and establishing operating parameters for candidate processes which yield equivalent performance and reliability with the standard process.

A recent example is the Pomona Virus Study (LACSD[6]), undertaken as a joint effort between DOH and the Los Angeles County Sanitation Districts. That study was conducted to establish filter design and operating criteria for the tertiary treatment plants described above. The starting point for the study was DOH's standard technology of activated sludge followed by chemical coagulation-sedimentation-inert media filtration-chlorination. This process--System A in Table 2--is very costly for general use due to high chemical dosages, and was known to have the drawbacks of increased effluent TDS and a substantial sludge stream. A two-year study was undertaken to determine whether direct inert-media (System B) or activated carbon filtration (System C) could be operated to yield equivalent virus removal performance. In October 1978, DOH issued the filter design and operating criteria[13] identified in Table 2. These criteria are now available for statewide use in designing reuse systems. The key, of course, was establishing the technology-based standard as a starting point.

An equally constructive step taken in the past year by DOH has been to establish the Irvine Ranch Water District (IRWD) plan as the prototype for suburban dual systems throughout the state. Irvine's system involves tertiary effluent, treated to meet the Table 2 criteria, in a variety of irrigation applications, including domestic lawn-watering. The Table 2 criteria, with standard reliability and cross-connection prevention measures, are deemed adequate for park, playground, and schoolyard use--but are not sufficient in themselves for domestic sprinkler use. The solution accepted by DOH was to sell reclaimed water through homeowner associations, who in turn administer the irrigation of green spaces and suburban lawns under strict controls. Individual residents do not have access to the reclaimed water. Additional State requirements on the non-potable system consist of: non-standard threading, color coding of pipes, special connectors between the street connection and the sprinkler grid, no hose bibbs on non-potable system, backflow prevention devices, and others. These precautions ensure against accidental cross-connection with the potable system. design The complete set of design standards and separation requirements between potable and non-potable systems is too complex to cover here, but has been codified by the Irvine Ranch Water District into a set of design standards and operating specifications (IRWD[5]). Again, the key point is that any community in California can utilize the Irvine system as a prototype and demonstrate to the DOH that their project equals the Irvine prototype in safety and reliability.

The major remaining exception where technology standards have not been established for new projects is groundwater recharge by means of surface spreading and percolation. A cooperative study is now underway between DOH and LACSD to examine the Whittier Narrows recharge project as the first step in setting uniform criteria for recharge operations. This effort, which is described in detail by a companion paper being presented at this Conference (Nellor[7]), is expected to have far-reaching implications, not only for engineered recharge projects, but also for the many unplanned, incidental recharge operations found within the State.

THREE STEPS FOR A REGIONAL PLAN FOR EXPANDED REUSE

Simply stated, there are three main barriers to reuse. They are not barriers to building projects, but are barriers to defining projects. The three key problems are (1) the lack of technology standards (design criteria) for groundwater recharge, (2) the need to establish the location, quality requirements, and actual demand for reclaimed water in terms of willingness to pay, and (3) the lack of regional or combined state/regional financing methods, such as are used for conventional water supply development. To deal with these problems, the Study has recently awarded three contacts:

HEALTH STUDIES (Los Angeles County Sanitation District; $990,000)

Objective: In collaboration with the California Department of Health (DOH), obtain data to be used by DOH to develop project criteria and standard technology for groundwater recharge.

Scope: Scientifically assess existing groundwater recharge programs with regard to the effect of trace organic compounds in recharge waters. Scope of work includes hydrogeology of reclaimed water movement in aquifers, GC/MS characterization of organics in reclaimed, imported, and affected well waters; Ames and mammalian cell testing to assess toxicologic properties of reclaimed, imported, and affected well waters; and epidemiologic surveys of historic reuse programs.

Concept: This work closely follows the recommendations of the State's Blue Ribbon Consulting Panel Report[12] of June 1978, which prescribed a comprehensive assessment of existing programs. The logic is to attack the problem of trace organics head-on by identifying the specific compounds in reclaimed waters, determining whether breakthrough occurs during percolation through the soil, determining the exposure of the population to trace levels of organics, and obtaining presumptive evidence of chronic toxicity. This work is being coordinated with pilot testing of processes to determine performance in organics removal.

MARKETING & PROJECT FEASIBILITY (James M. Montgomery, Consulting Engineers, Pasadena; $685,000)

Objective: To determine the demand for reclaimed water; to establish reuse project feasibility and purveying arrangements in service areas throughout the Study Area.

Scope: Identify water suppliers, distributors, and selected retail purveyors in the Study area; project future domestic water rates at the wholesale and retail levels, allowing for uncertainties in the cost of imported water supplies.

Prepare cost estimating curves for pump stations, pipelines, operating storage, treatment works, and industrial pretreatment for use in preliminary design of reclaimed water distribution networks; develop hydraulic models as needed to screen and size delivery systems; check cost curves against recent contract award data and current design and construction practices.

Contact water purveyors to determine their interest and financial ability to construct and operate reclaimed water delivery systems. With purveyor support, contact interested end users and obtain site data such as piping plans, locations of booster pumps and storage lakes, determine average and seasonal water use, potable/non-potable system separation, and other relevant on-site engineering features.

Identify prospective water reuse service areas based on purveyor and user interest, and organize water reuse advisory committees for each service area.

Perform field surveys to determine users' on-site cost to convert to reclaimed water. Determine users' willingness to pay for reclaimed water in terms of a discount off projected domestic water rates. Perform engineering design of alternate delivery systems, and determine system costs. Identify feasible projects, purveying arrangements, and obtain users' letters-of-intent. Prepare regional priority list of projects for grant funding and submit to SWRCB Office of Water Recycling. Prepare service area engineering report on near-term and ultimate reuse feasibility.

Concept: This work places heavy emphasis on industrial and irrigation applications, in an attempt to establish the actual market for direct non-potable water reuse. In effect, the Study is making Montgomery available as consultants to prospective water purveyors and end-users. A "from the top down" marketing approach is being taken, working from water wholesaler to retailer to user--the chain of project implementers.

The idea is to perform all preliminary engineering necessary to establish reuse as a standard class of service in service areas throughout the Study Area.

ECONOMIC, FINANCIAL, AND INSTITUTIONAL BASIS FOR LARGE-SCALE REUSE
(The Metropolitan Water District of Southern California; $210,000)

Objective: To establish the economic basis and financial arrangements for developing water reuse as a resource of statewide value.

Scope: Determine the economic value of water reuse as an element of California's water development strategy. Compare the cost of reuse with the alternative cost of new reservoir capacity in the north. Analysis will include dependable yield of present water supplies, projected water demands, detailed cost of SWP expansion to meet water demands with and without expanded reuse, and cost-effectiveness of reuse relative to equivalent reservoir capacity.

Document the distribution of reuse project benefits and costs among regions of the state, and among local user classes. Identify any local water rate increases caused by expanded reuse. Identify regional and statewide methods for project finance which will fund reuse at its real economic value, and minimize inequities.

Prepare a financial plan (or plans) for large-scale reuse, including all necessary transfer payments, imported water credits and tax credits for users' on-site investment. Identify legal and legislative initiatives needed to implement the plan(s).

Concept: The logic is to establish water reuse as a credible water supply increment under the Marketing and Project Feasibility task and then establish the necessary statewide financing mechanism under the Economic, Financial and Institutional task. The purpose is to integrate reuse formally into state-level water development on the same cost-effectiveness and financial basis as other water supply options.

SUMMARY

In summary, the barriers to reuse are organizational. For example, agency responsibilities for marketing and project financing are not well-defined. Responsibility for water reuse is divided between the traditional roles of the water supply and wastewater treatment communities. However, the availability of reclaimed water, the demonstrated need for additional water, and the reality of water shortages--all provide the justification for a unified effort among water and wastewater agencies, supported by community and state leaders, to support of cost-effective reuse projects.

The Study will yield an engineering plan and a redefinition of agency roles needed to implement that plan. The output of the Study will be a regional Facilities Plan for expanded water reuse. The Facilities Plan will include (1) a list of projects, (2) preliminary engineering for those projects, including plant designs and delivery system layouts, physical capacities and sizing, cost estimates and revenue needs, (3) financing plans, with purveying and ownership arrangements, and (4) implementing actions and agency roles needed to carry out the Plan. The Plan is being developed in close contact with engineering professionals, elected officials, and the community at-large, in order that the findings will be publicly acceptable and implementable upon completion of the Study. The Management Board will approve the Facilities Plan and transmit it to all participating agencies and implementing agencies with a request for their formal action--expression of support, approval, or adoption, as appropriate.

. . .

FOOTNOTES

1. ARGO, DAVID G., "The Cost of Water Reclamation by Advanced Wastewater Treatment," presented at the WPCF 51st Annual Conference, Anaheim, (October 1-6, 1978).

2. CROOK, JAMES and SPATH, DAVID P., "Wastewater Reclamation In California," To be published in the proceedings of the AWWA Water Reuse Symposium, March 25-29, 1979, Washington D.C., (In preparation)

3. FLETT, DOUGLAS B., "Wastewater Reclamation for Industrial Use," Journal AWWA, (February 1975).

4. Irvine Ranch Water District, "Detailed Reclaimed Water Plan for Irvine Ranch Water District," Irvine, California (1975).

5. Irvine Ranch Water District, Rules and Regulations for Water, Sewers, and Reclaimed Water Service, Resolution No. 19744-49 of the Board of Directors of IRWD, effective (June 1, 1977).

6. Los Angeles County Sanitation Districts, Pomona Virus Study, Final Report submitted to the State Water Resources Control Board and published in June 1977.

7. Los Angeles County Sanitation Districts, "Health Effects of Groundwater Recharges," M. Nellor, to be published in the proceedings of the AWWA Water Reuse Symposium, March 25-29, 1979 (In preparation).

8. Orange and Los Angeles Counties Water Reuse Study, Phase I Report & Work Plan, and separately bound Health Effects Work Plan, approved for publication on October 17. 1978.

9. State of California, Water Resources Control Board, "Wastewater Reclamation at Whittier Narrows," A Final Report by F. C. McMichael and J. E. McKee, W. M. Keck Laboratory, California Institute of Technology, Pasadena, Published 1966.

10. State of California, Department of Water Resources, The California Water Plan, Outlook in 1974, DWR Bulletin No. 160-74, November 1974.

11. State of California, Wastewater Reclamation Criteria, an excerpt from the California Administrative Code, Title 22, Division 4, Published by Department of Health, Berkeley, 1975.

12. State of California, Water Resources Control Board, Report of the Consultation Panel on Health Aspects of Wastewater Reclamation for Groundwater Recharge, Sacramento, Jan. 1976.

13. State of California, Department of Health, Memorandum from Henry J. Ongerth (State Sanitary Engineer) to Neil Dunham (Manager, Clear Water Grant Program), Subject: Virus Study, April 28, 1978.

14. State of California, The California State Water Project--1977 Activities and Future Management Plans DWR Bulletin No. 132-78, Sacramento, October 1978.

15. The Metropolitan Water District of Southern California, Planning Concepts Used In Determining the Water Supply Available from the State Water Project, Report No. 935, Los Angeles, January 1979.

16. WOODBURN, JAMES D., "Use of Reclaimed Wastewater for Power Plant Cooling Tower Make-Up," City of Burbank, Public Service Department, Paper presented at the California Office of Water Recycling's Industrial Water Reuse Conference, Culver City, October 31, 1978.

TABLE 1

Tertiary Treatment Plant Capacities and Typical Effluent Characteristics[1]

EXISTING FACILITY	PLANT CAPACITY AND TYPICAL EFFLUENT CHARACTERISTICS					
	Capacity AFY	TDS mg/l	Hardness mg/l	BOD_5 mg/l	SS mg/l	Turbidity JTU
Burbank WRP	9,000	550	180	NA	2	<2
LA-Glendale WRP	20,000	600	95	5	5	<2
Whittier Narrows WRP	14,000	575	175	5	2	<2
San Jose Creek WRP	37,500	675	225	5	2	<2
Pomona WRP	10,000	550	200	3	1	<2
Los Coyotes WRP	37,500	850	250	4	3	<2
Long Beach WRP	12,500	750	200	3	3	<2
Water Factory 21	15,000	400	126	0	0	<0.5
Michelson WRP	6,600	850	NA	NA	3	<2

[1] All facilities utilize activated sludge secondary plus dual-media effluent filters, except Water Factory 21 which provides lime clarification, ammonia stripping, activated carbon control, reverse osmosis, and blending with deep-well pumpage.

TABLE 2

Basic Filter Design and Operational Requirements
for Body-Contact Recreation and Spray
Irrigation Modes of Reuse[1,4]

PARAMETER	UNITS	REQUIREMENTS FOR EQUIVALENT TREATMENT PROCESSES		
		System A (COAG-SED-FILT-Cl_2)	System B (COAG-FILT-Cl_2)	System C (CARBON FILT-Cl_2)
Secondary Effluent Turbidity	JTU	Not Spec.	<10	<10
Coagulant/ Rapid Mix		Req'd.	Req'd.	Not Req'd.
Filter Media[2]		Coal-Sand (1.1mm)(0.57mm)	Coal-Sand (1.1mm)(0.57mm)	Activated Carbon (0.8 - 0.9mm)
Filter Bed Depth[2]	Ft.	3 (+ support)	3 (+ support)	3 (+ support)
Filter Loading Rate[2]	GPM/ft[2]	5	5	3½
Filter Contact Time[2]	Minutes	10	10	10
Tertiary Effluent Turbidity (Average)	JTU	≤2	≤2	≤2
Chlorine Mixing Energy[2]		Not Spec.	High-energy mixing; comparable to 9 HP per million gallons as used in Pomona Virus Study.	
Chlorine Contact Time				
.Theoretical	HR	Not Spec.	2	2
.Modal	HR	Not Spec.	1½	1½
Chlorine Contact Chamber Dimensions		Not Spec.	40:1 length to width or depth	40:1 length to width or depth
Coliform MPN[3]	#/100 ml.			
.Median	last 7 days	≤2.2	≤2.2	≤2.2
.Maximum	All Samples	≤23	≤23	≤23
Chlorine Residual	mg/l	Positive residual, min. of 1 mg/l, exact level not specified.		

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[1] References: Memorandum, Henry J. Ongerth (State Sanitary Engineer) to Neil Dunham (Manager, Clean Water Grant Program), Virus Study, April 28, 1978.

Pomona Virus Study, Final Report, A Technical Report by the Los Angeles County Sanitation Districts Submitted to the State Water Resources Control Board, June 1977.

[2] The Department of Health, pursuant to Ongerth's April 1978 memorandum requires filter media, depth, loading rates and chlorine mixing energy "comparable" to those used in the Pomona Virus Study which are listed above. These are advisory, and reasonable variations will be approved.

[3] Per amendments to California Administrative Code, Title 22, §60313 (b), September 20, 1978.

[4] The design and operational criteria are augmented by reliability criteria under Calif. Admin. Code, Title 22, Articles 8-10. These call for alarms on unit processes, standby automatically-activated power supplies, provision for emergency storage or disposal in case of plant failure, and multiple or standby units for all processes.

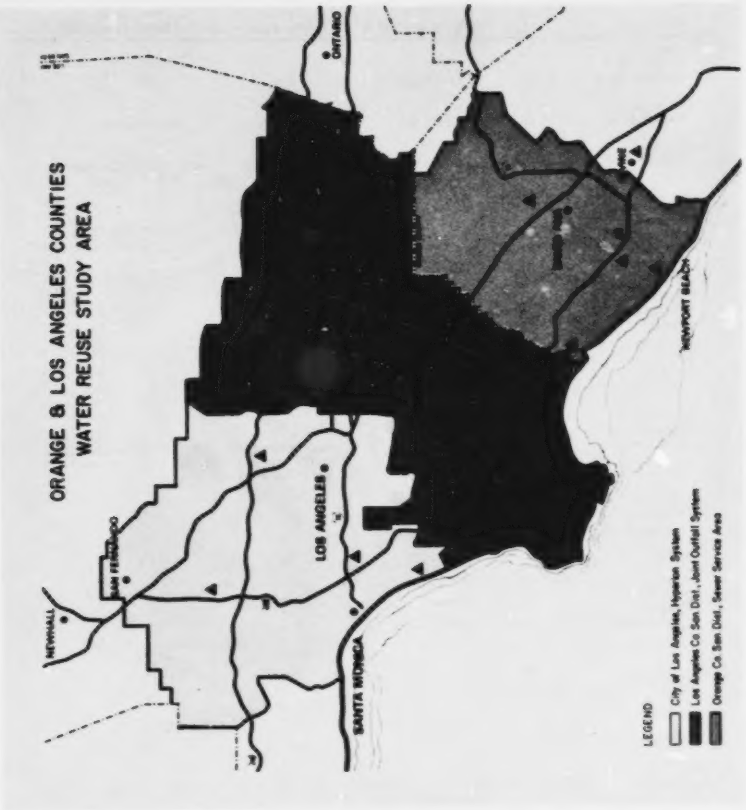

ORANGE & LOS ANGELES COUNTIES
WATER REUSE STUDY AREA
NEWHALL
SAN FERNANDO
LOS ANGELES
SANTA MONICA
ONTARIO
NEWPORT BEACH
LEGEND
City of Los Angeles, Hyperion System
Los Angeles Co San Dist., Joint Outfall System
Orange Co San Dist., Sewer Service Area

FIGURE 1
The Study Area spans two counties and more than 100 cities. It includes a population of 8½ million, with associated industry.

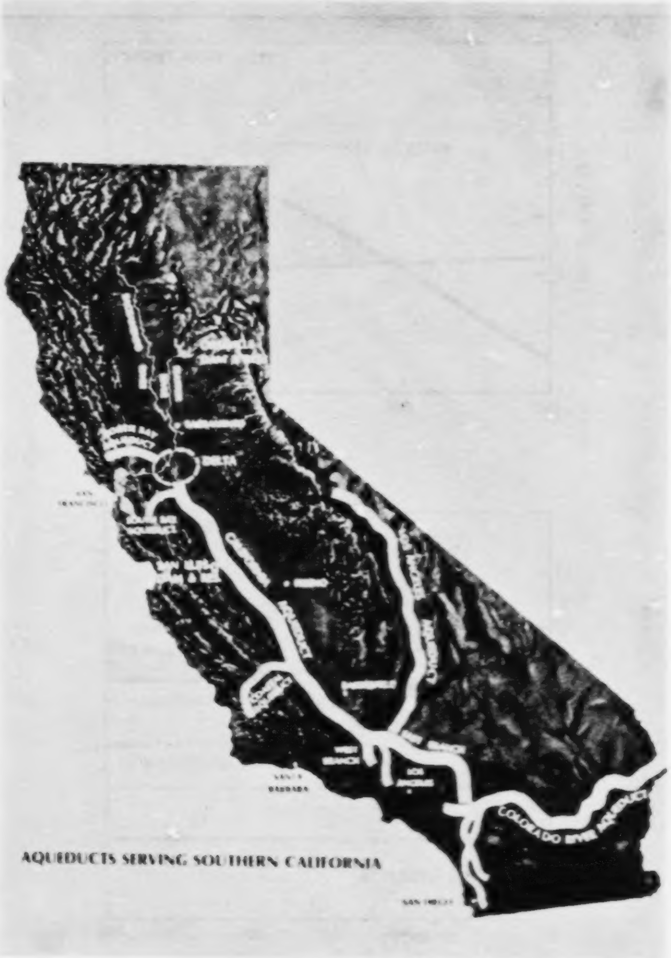


FIGURE 2
Two-thirds of the region's water supply is imported via the Los Angeles Aqueduct, the Colorado River Aqueduct, and the California Aqueduct.

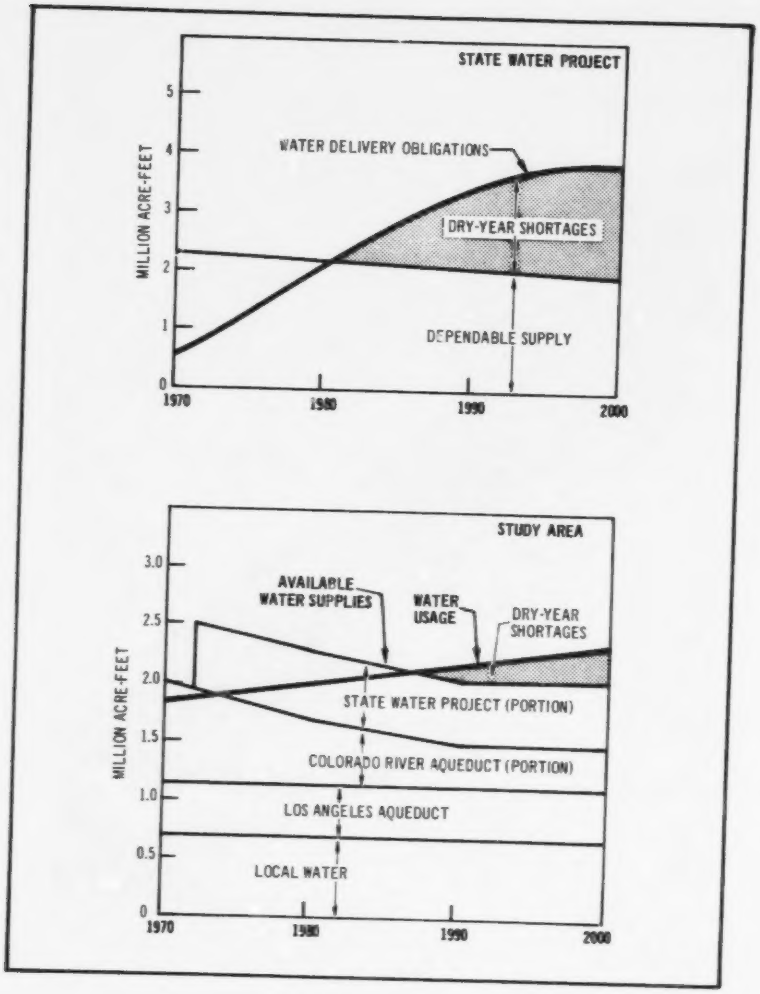


FIGURE 3

PROJECTED WATER NEEDS OF STUDY AREA (PRELIM.) Study area is assumed to receive a pro rata share of 60-65% of MWD's total delivery of SWP and Colorado River water. SWP dry-year shortages (at top) begin in early 1980's; normal rain-year shortages in mid-80's. Corresponding Study Area shortages begin in late-80's for dry years, early-90's for normal years.

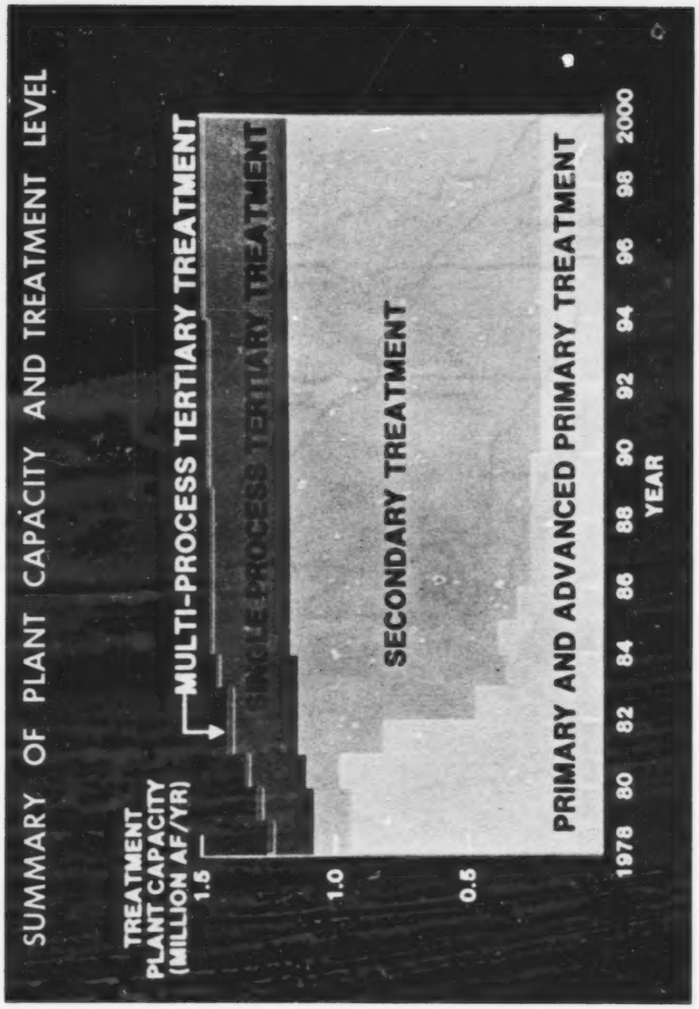
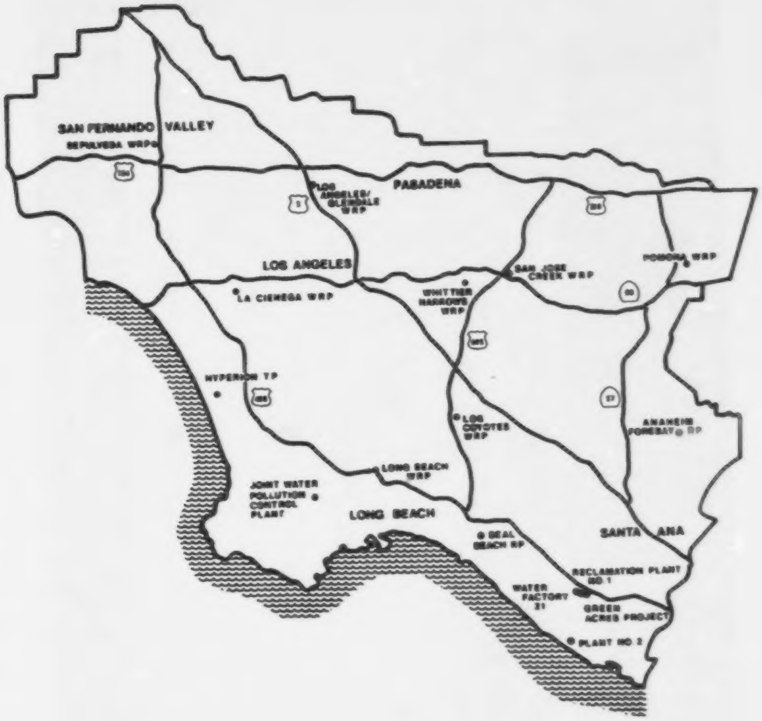

SUMMARY OF PLANT CAPACITY AND TREATMENT LEVEL
TREATMENT PLANT CAPACITY (MILLION AF/YR)
1.5
1.0
0.5
MULTI-PROCESS TERTIARY TREATMENT
SINGLE-PROCESS TERTIARY TREATMENT
SECONDARY TREATMENT
PRIMARY AND ADVANCED PRIMARY TREATMENT
1978
80
82
84
86
88
90
92
94
96
98
2000
YEAR

FIGURE 4

FIGURE 5

LOCATION MAP

WASTEWATER TREATMENT AND RECLAMATION PLANTS SERVING THE STUDY AREA.



GUIDELINES FOR IMPLEMENTING
A WATER-REUSE PROGRAM

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Under contract 68-03-2686 to the Environmental Protection Agency, the environmental consulting firm of Camp Dresser & McKee Inc. is currently completing a wastewater-reuse guidelines document that is designed for wide use by water-system managers, resource planners and others. We consider these guidelines to be of great significance to EPA efforts to promote the sound reuse of wastewater for nonpotable purposes, and, accordingly, we have made every effort to develop a document that is highly readable and useful.

In this document, we are attempting to reach every area of the country. We are convinced that it must address reuse needs that extend far beyond the arid Southwest, where reuse has become an essential planning tool for water managers (Figure 1). There is every reason to believe that increasingly, other areas of the country will need to draw from the experience of reuse planning and implementation in arid areas.

In communities where:

- freshwater supplies are limited;
- freshwater supplies of good quality are limited by surface or groundwater pollution,
- new freshwater supplies must be developed at increasing distance from and/or expense to the community;
- a single large water user or class of users can tolerate a lower grade of water provided at reasonable cost, and/or
- receiving-water quality requirements are such that costly wastewater-treatment facilities must be built,

wastewater reuse may offer some very real community benefits:

- an increase in total available water supply,

- conservation of highest-quality supplies for potable use and other uses that demand that quality,
- expansion of beneficial industrial, commercial, agricultural or recreational opportunities in an area, and/or
- obtaining of capital and operating economies in a water-management program.

Obviously, these considerations apply to many areas outside "the arid Southwest," if not to most areas of the United States. Even those areas of the country that have always been considered water-rich are encountering serious water-supply problems -- and projections of shortages or expensive treatment requirements in the near future. Excessive demand, contamination by synthetic organics, and saltwater intrusion of aquifers are just some of the kinds of water-supply problems being faced.

Water reuse is no panacea for these problems. Typically, however, it has not even been considered as a planning alternative for water-supply development. We can no longer afford to take so narrow an approach to water management in the United States.

AN EXAMPLE IN THE NORTHEAST

An example of how the EPA water-reuse guidelines documents could be applied to the "water-rich" Northeast can be found in eastern Massachusetts. Figure 2 illustrates a 98-community planning area surrounding the city of Boston. Cities and towns in this area have been served by a variety of surface- and groundwater sources; more than 30 are served by the Boston Metropolitan District Commission (MDC), which, in the 1930s, developed its Quabbin Reservoir supply in the central part of the State. Virtually all of these 98 communities face water-supply problems. Separate reports published by federal, regional and local agencies early in the 1970s pointed out the need for augmenting water supplies in the area (Refs. 1, 2). One report stated that only two of the 98 communities have existing supplies sufficient for 1990 demands; only 17 have potential supplies that together with existing supplies could meet the 1990 demand.

Strategies developed in the late '60s and early '70s for meeting the projected shortages involved:

- diverting Connecticut River floodwaters to the Quabbin Reservoir,
- constructing a large (up to 500-mgd) facility for treating Merrimack River waters, and/or
- developing additional local surface- and groundwater supplies.

In general, strategies of water conservation and wastewater reuse were not examined closely 10 years ago. But problems with the proposed alternatives have become increasingly apparent. Diversion of the Connecticut River waters to the Quabbin will entail considerable expense, will necessitate filtration of the Quabbin supply and will create institutional and political problems. (In fact, an environmental impact assessment for the diversion is currently under way; the project will probably proceed contingent upon the institution of far-reaching water-conservation measures.) And, although the quality of the Merrimack River waters is measurably improving as new biological wastewater-treatment plants come on-line, protection of the public health demands a high degree of treatment prior to potable reuse. The treatment costs will certainly soar if proposed EPA amendments for control of trihalomethanes and synthetic organic contaminants are effected. Many communities that use groundwater supplies have fully exploited these sources. In some cases, too, organics have shown up in groundwater.

One lesson that could be drawn from the water-supply problems in eastern Massachusetts is that quality upland supplies should be conserved for potable use. Water managers would then be free to explore the use of lower-quality river sources and/or reclaimed water for industrial, agricultural, commercial and domestic nonpotable applications. It is to this end that the guidelines have been produced.

ORGANIZATION AND USE OF THE GUIDELINES

Two positive factors offer renewed hope for management of water resources:

- the development of technology capable of treating wastewater to a point that renders it a commodity "too good to throw away,"
- the increasing, and, in some cases suprisingly high, social acceptability of water reuse for several nonpotable purposes (Ref. 3).

Recognizing all of these factors, EPA identified in 1978 an immediate short-term objective of developing a guidelines document that will significantly increase interest in and assist implementation of wastewater reuse. The guidelines document, now nearing completion, emphasizes nonpotable reuse such as irrigation and agriculture, industrial, recreation and other nonpotable urban uses, recognizing that direct potable reuse will require significant further research and demonstration. The wastewater-reuse guidelines will make water managers and resource planners aware of the proven reuse possibilities that might exist nearby, and the guidelines user will know that EPA is encouraging this approach.

The guidelines are organized around the principal areas of concern in reuse planning. Separate chapters address technical, economic, legal/institutional, financial, marketing and public-involvement issues. The nature of these areas of concern is examined in sufficient depth so that the guidelines user can estimate the complexity of the implementation problem and the effort required to overcome it. Throughout, case histories provide concrete examples of the opportunities and problems encountered by municipalities and water-supply regions that have implemented water-reuse programs of varying scale.

Chapter-by-chapter, the guidelines include discussion of the following issues:

Technical Issues

Guidelines are presented for locating sources of reclaimed water, and establishing markets for agricultural, industrial, domestic, commercial and recreational uses. Case studies are used in assisting the planner to locate suitable sources and markets. Factors addressed include:

- characterizing effluent quality and quantity,
- determining quantity and quality of the various uses,
- determining treatment requirements of the effluent, either at the site of the wastewater-treatment plant or at the point of use. Water quality and treatment requirements are suggested for nonpotable urban reuse, agriculture, recreation, groundwater recharge and industrial uses (Fig. 3),
- quality assurance.

Economic Issues

The essence of the guidelines is considered here, the cost comparison between freshwater and reclaimed water systems. Methods are proposed for (1) establishing the present and projected costs of freshwater to the potential local users of reclaimed water, and (2) comparing these freshwater costs to the estimated costs of using reclaimed water.

The bulk of this section is dedicated to a step-by-step discussion of methods to determine the total reclaimed water system costs, including (1) costs for additional treatment, if necessary (e.g., Fig. 4), (2) costs for storage, if necessary, and (3) costs for conveyance/distribution (Figs. 5 and 6). "Reconnaissance-level" costs are included.

Legal/Institutional

An overview of the issues is provided, telling what can and cannot be done and, in the case of the former, how it must be done. Points of discussion include (1) the legal issues associated with reuse; (state statutes, state enabling legislation, water rights law, franchise rights, and case law); (2) the organizations involved, (local, state and federal), the regulations promulgated by each, and the review procedures used by each; and (3) general steps that should be followed throughout implementation of a reuse project (maintaining contact with agencies, developing schedules, cash flow needs, institutional alternatives (Fig. 7), contracts).

Financing the Reuse Program

Federal funding sources are examined and include (1) EPA (innovative treatment technology, reclaiming and reuse of water), (2) Farmers Home Administration, (3) the Bureau of Reclamation, and (4) the Small Business Administration. State and local support are discussed, followed by a discussion of user charges, property tax and special assessments.

Marketing the Resource

This is the first step toward implementation of a reuse program. Guidelines are proposed for:

- "selling" the reuse concept
- recognizing and avoiding risks
- selecting the type of reuse project
- owning and operating treatment facilities
- dealing with "the competition"
- approaching funding sources
- closing the sale

Public Acceptability and Public Support

Positive public acceptance of water reuse is often underestimated. The guidelines outline ways to test public opinion, including opinion surveys (often misrepresentative if made by non-professional). Other sources include (1) published studies and, (2) local special interest groups and citizen organizations. Support should be sought from local medical and public health authorities.

Evaluation of information is discussed, as is the building of public support by:

- identifying key individuals
- organizing these key individuals into a working coalition for wastewater reuse
- letting the coalition plan the implementation

As mentioned previously, among our principal concerns has been to make the guidelines a working document, useful and interesting, both for the water manager and resource planner. To this end, we have formulated an integrated, step-by-step approach that a serious planner can follow to gain a clear indication of the feasibility of reuse in the community.

This staged planning approach is illustrated in Figures 8-11, delineating the major tasks that could appropriately be performed at each stage. These tasks range from the most elementary -- locating sources of wastewater -- to the most highly detailed -- developing "reconnaissance-level" cost estimates of key elements in the selected reuse system.

Each stage of activity builds on previous stages until there is enough information to develop a conceptual reuse plan for the community or region and to begin negotiating the details of reuse with the selected users. The use of straightforward language and bold graphics make the guidelines interesting and easy to follow.

An Answer to the Need

Sufficient water is available in most regions of our country for many years to come. Sources of quality water are not, however, close to the centers of demand, and conveyance of the waters to users is often expensive and institutionally and politically difficult. We fully expect that the guidelines will draw attention to the neglected resource of reclaimed water as a viable source of water to the public and to industry for nonpotable uses; thus conserving freshwaters for the highest uses, including drinking and bathing.

GUIDELINES FOR IMPLEMENTING REUSE

(ENVIRONMENTAL PROTECTION AGENCY
CONTRACT NO. 68-03-2686)

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- Identifying Key Opinion Leaders

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Figure 1

AREAS FACING CRITICAL
WATER SHORTAGES

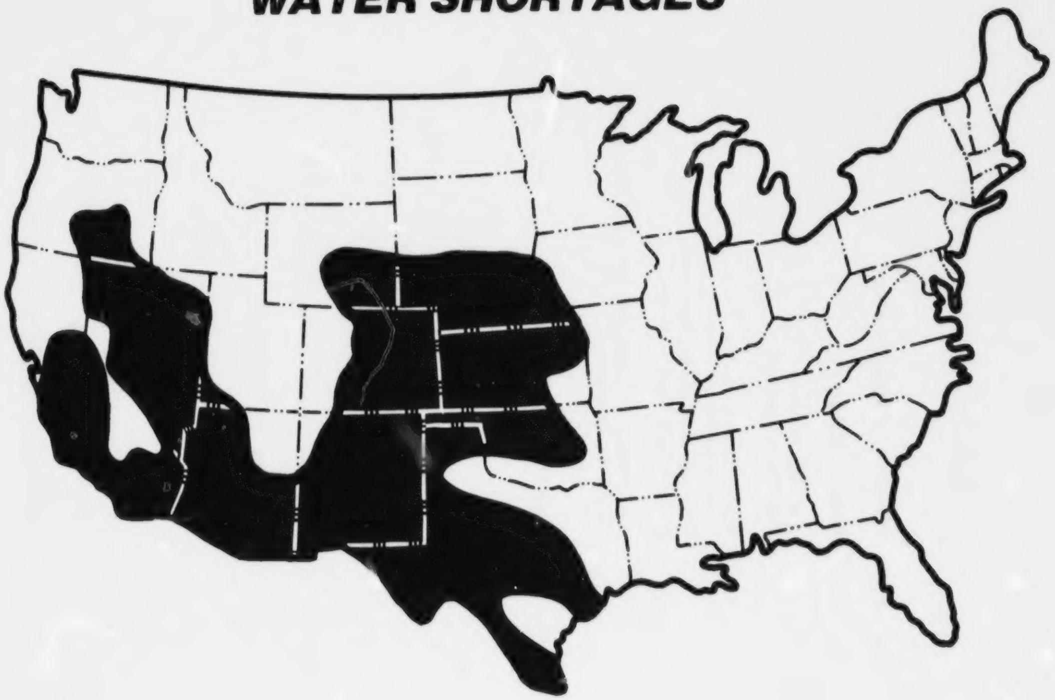


Figure 2

WATER SUPPLY ALTERNATIVES
FOR EASTERN MASSACHUSETTS

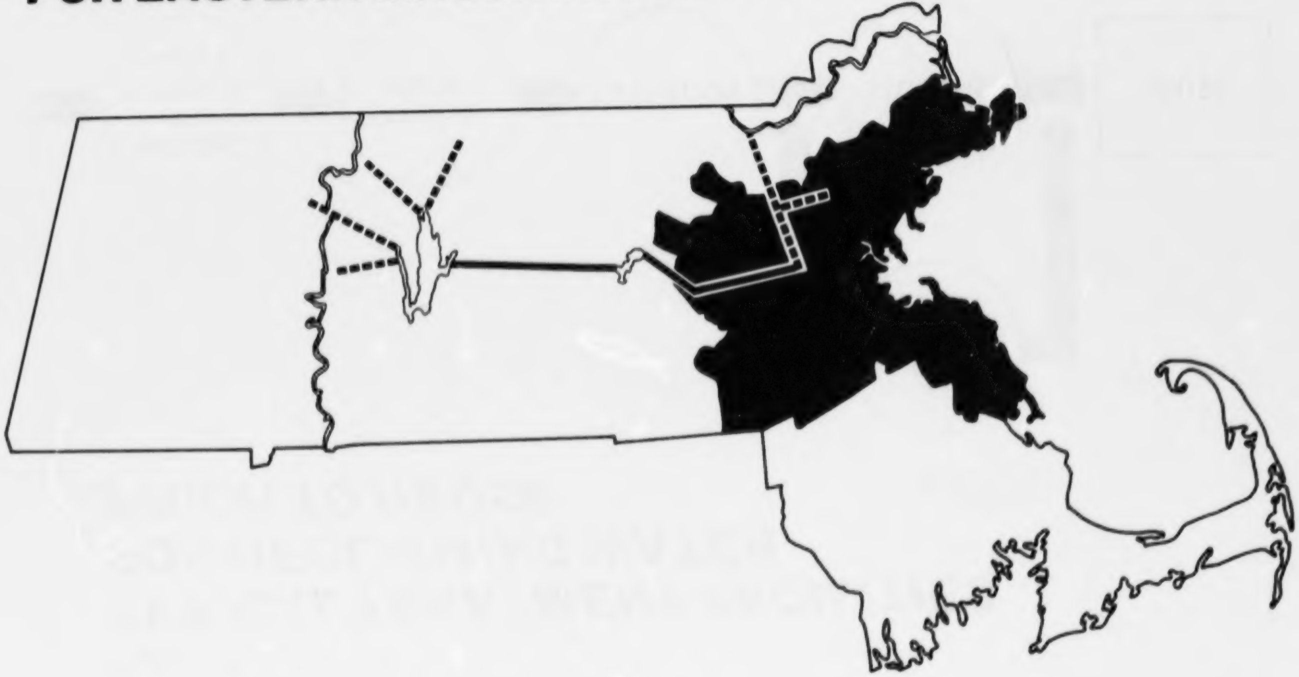
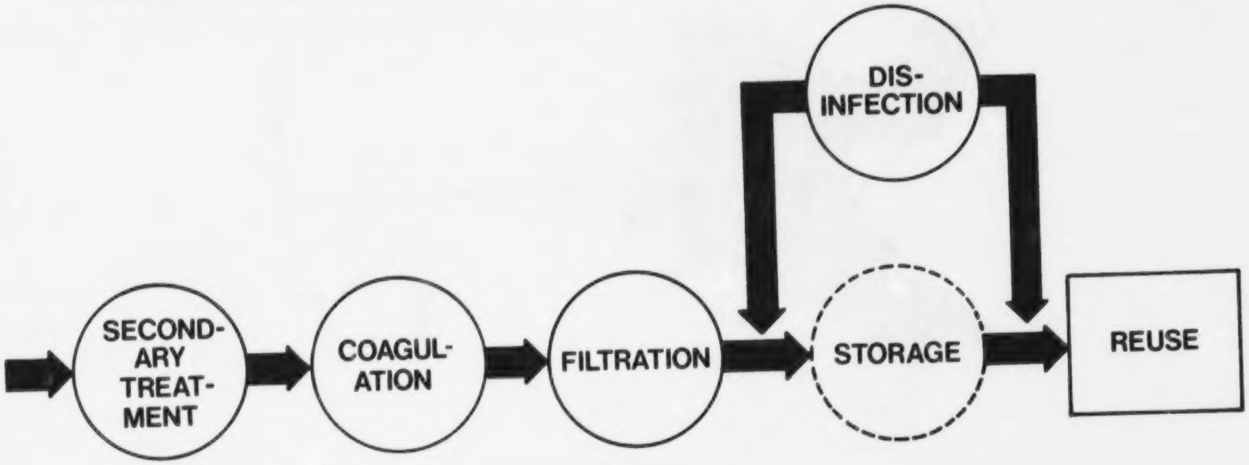


Figure 3

TYPICAL TREATMENT FACILITIES FOR RECLAIMING WATER PRIOR TO REUSE



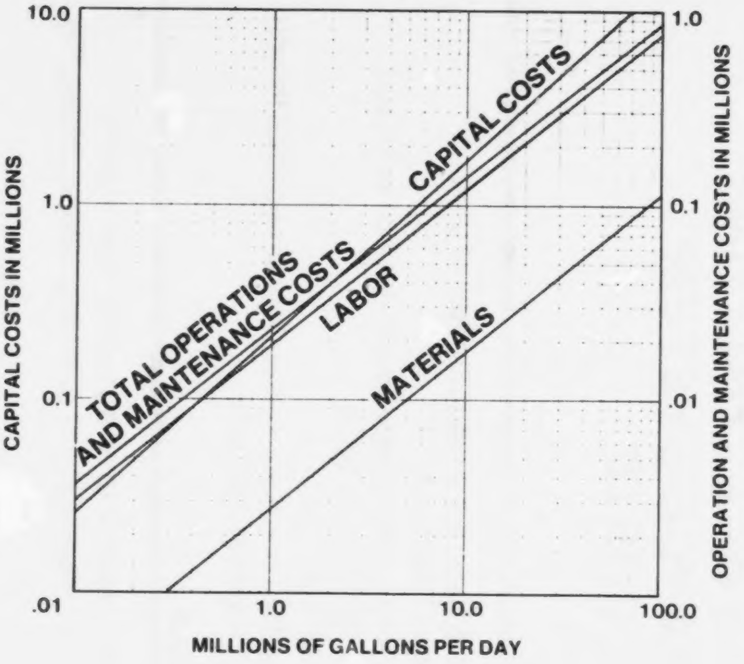


Figure 4

COSTS OF FILTRATION

Figure 5

METHODS OF ESTIMATING CONVEYANCE-SYSTEM CAPITAL COSTS

Force Mains

1. Determine suitable diameter of pipe (Eqn. 1 or Fig. 3-1)
2. Determine cost-per-linear-foot of selected diameter force main (Fig. 3-2)
3. Multiply cost-per-linear-foot times total length of conveyance route

Pump Stations

1. Determine Q (average daily flow in gpm)
2. Determine costs of pumping system, using Fig. 3-3

Figure 6

METHODS OF ESTIMATING CONVEYANCE-SYSTEM O&M COSTS

Power Costs

1. Determine static head (change-in-elevation from point of effluent discharge to point of reuse), using USGS map
2. Using known pipe diameter and average daily flow, determine friction head loss (Fig. 3-4)
3. Determine horsepower requirements (Eqn. 2)
4. Calculate local annual power costs (Eqn. 3)

Labor Costs

Labor costs are based on estimated operational hours and local wage rates.

Materials and Maintenance Costs

Figure 7

WHO SHOULD OPERATE THE AWT FACILITIES?

The industry. . .

- Tax and/or depreciation advantages
- Close control of reclaimed-water quality
- Availability of skilled personnel

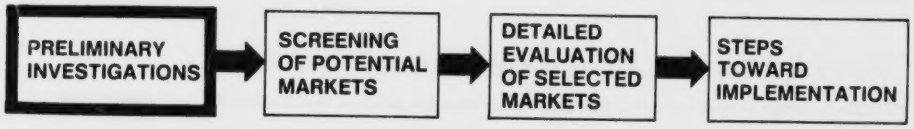
. . .the municipality. . .

- Economies of scale in addition to existing facility
- Ability to service more than one user

. . .or some form of split ownership/operation

Figure 8

A PLANNING APPROACH TO REUSE


PRELIMINARY INVESTIGATIONS
SCREENING OF POTENTIAL MARKETS
DETAILED EVALUATION OF SELECTED MARKETS
STEPS TOWARD IMPLEMENTATION

Technical

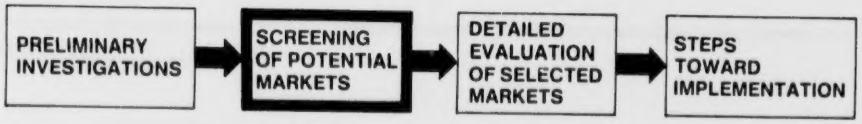
- Locate sources
- Locate markets

Legal/Institutional

- Review applicable legislation

Figure 9

A PLANNING APPROACH TO REUSE


PRELIMINARY INVESTIGATIONS
SCREENING OF POTENTIAL MARKETS
DETAILED EVALUATION OF SELECTED MARKETS
STEPS TOWARD IMPLEMENTATION

Technical

- Match source quantity/quality to user requirements

Economic

- Determine present/projected water-supply costs

Legal/Institutional

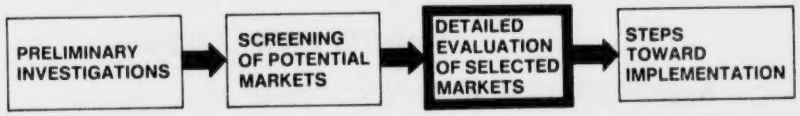
- Identify responsible agencies
- Review pertinent regulations

Financing

- Identify sources of funding support

Figure 10

A PLANNING APPROACH TO REUSE


PRELIMINARY INVESTIGATIONS
SCREENING OF POTENTIAL MARKETS
DETAILED EVALUATION OF SELECTED MARKETS
STEPS TOWARD IMPLEMENTATION

Technical

- Determine need for additional treatment
- Determine storage/treatment requirements

Economic

- Estimate total costs of reclaimed water & compare to freshwater costs

Legal/Institutional

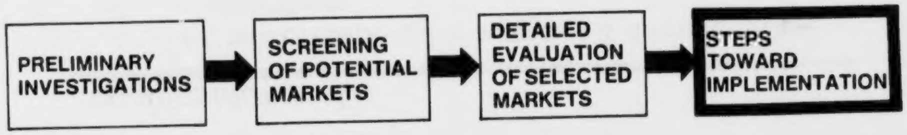
- Contact responsible agencies & discuss review procedures

Financing

- Assess cash-flow needs
- Contact funding agencies

Figure 11

A PLANNING APPROACH TO REUSE



PRELIMINARY INVESTIGATIONS
SCREENING OF POTENTIAL MARKETS
DETAILED EVALUATION OF SELECTED MARKETS
STEPS TOWARD IMPLEMENTATION

- *Develop conceptual plan*
- *Outline realistic schedule*
- *Approach prospective users*
- *Approach funding agencies*
- *Plan for system safety and reliability*
- *Solicit public support*
- *Negotiate user charges*

WASTEWATER RECLAMATION FOR THE SAN FRANCISCO BAY REGION

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INTRODUCTION

Two major factors have contributed to the interest in large-scale water reuse in the San Francisco Bay Area--one, a shortage of water supply, and two, construction of new wastewater treatment plants producing usable water. Treated wastewater is presently discharged to San Francisco Bay and the Pacific Ocean and is lost from the freshwater resources of the state.

The recent drought led to new, lower projections of the safe yield of California's water resource systems. Some agencies estimate the post-drought yield at about 70 percent of the predicted yield prior to the drought. These new lower estimates of available supply came at the same time the California State Water Resources Control Board passed Decision 1485 which developed new water quality standards for the Sacramento-San Joaquin Delta area. Decision 1485 resulted in increased requirements for outflow of freshwater through the Sacramento-San Joaquin Delta into San Francisco Bay in order to meet water quality standards. This led to increased concern about the need for additional increments of water supply.

San Francisco Bay Area wastewater agencies are all providing, or will soon provide, secondary treatment, and in some cases, advanced wastewater treatment. Many major water users could use this reclaimed water.

The San Francisco Bay Area Water Reuse Study is an effort to try to solve a part of the water supply needs of the state by large-scale recycling. In recognition of this potential, seven major Bay Area water and wastewater agencies, plus seven state, federal, and regional regulatory agencies formed a joint powers agency to study the potential for large-scale water reuse. A policy board of these agencies was formed to direct the study.

It was recognized at the outset that there were major hurdles to overcome before a regional project could be implemented. Thus, a phased approach was used. The first phase is a 7-month effort to determine if there really are practical, large-scale recycling projects. Depending on the outcome of the first phase a second phase is included, to study the projects which seem practical in more detail. Total funds available for the 3-year project are $2 million. The commitment of funds for Phase I is $325,000.

As of today, we are approximately two-thirds of the way through the first phase.

For sources of wastewater, the study area included the nine-county Bay Area. Potential markets included a much wider area, as shown in Figure 1.

BACKGROUND INFORMATION

There were two major efforts required in gathering background information. The first was to review previous studies, primarily those by the California Department of Water Resources which had previously studied large-scale reuse of Bay Area wastewater. The second was to update information on the wastewater sources, taking into account the impact of water conservation during the drought, wastewater quantities, effluent quality, and the extent of existing reuse.

The review of wastewater sources yielded some interesting conclusions:

- Even though water use is still below the pre-drought demands, wastewater quantities have increased to pre-drought levels. That is, the current savings in water use seem to be in uses which do not end up in the sewer system, like landscape irrigation.
- Wastewater quantities from the area are presently about 530,000 acre-feet per year and will increase to 800,000 acre-feet per year by the year 2000. However, due to geographic constraints and local reuse projects, only about 440,000 acre-feet can be collected for reuse.
- In the aggregate, the wastewater will have total dissolved solids content of approximately 1,000 milligrams per liter. Source control programs, primarily controls on water softener regeneration, could reduce this to approximately 700.
- All the wastewater agencies are either providing secondary treatment or have secondary treatment under construction. Several have advanced waste treatment including coagulation, sedimentation, nitrification, and filtration.

Another interesting conclusion was the extent to which local reuse projects have proliferated in the past 5 years. Earlier estimates of the potential for reuse in the nine-county Bay Area were on the order of 50,000-60,000 acre-feet per year. The current update showed estimates on the order of 100,000-120,000 acre-feet per year of reuse for local projects.

There is a long list of existing reuse projects, with a variety of uses as shown below, but most are small in size:

- Landscape irrigation
- Agricultural irrigation
- Industrial cooling
- Marsh enhancement
- Saltwater intrusion barrier

MARKETING

Finding major potential markets for reclaimed water involved three basic steps: a series of brainstorming sessions on possible uses of reclaimed water, interviews with 70 potential reclaimed water users, and reviews of recent published data.

The brainstorming sessions resulted in an "Idea Generation Report" through the use of formalized brainstorming sessions, similar to those used routinely in the value engineering process. This resulted in a long list of small interesting reuse applications and provided a good "laundry list" of possible "spin-off" projects which could be considered along with a regional project.

It was also concluded as a result of the brainstorming session, however, that major markets were needed to justify the expense of a large-scale regional project. Major markets which resulted from the review of published information and which were confirmed through interviews with potential users included the following:

- Salinity control in the Delta, which could use 300,000-600,000 acre-feet per year
- Management of Suisun Marsh on the western edge of the Delta - 150,000 acre-feet per year
- Powerplant cooling in the Delta area - 30,000 acre-feet per year
- Agricultural use in Solano County, north of the Delta - 100,000 acre-feet per year
- Agricultural use in the northern and southern San Joaquin Valley, south of the Delta - 600,000 acre-feet per year

Since the wastewater flow available is only 440,000 acre-feet per year, it was apparent that the total available supply of reclaimed water is not sufficient to meet all of the potential markets.

A major conclusion from the interviews with potential users of reclaimed water was that there is no market unless the price of reclaimed water is competitive with alternative sources of supply! This emphasized the importance of finding a funding mechanism which would permit pricing reclaimed water at prices competitive with conventional supplies.

Recognizing the importance of this issue, the State Department of Water Resources prepared estimates of the cost for the next increment of conventional supply for Northern California. Two different alternatives were considered. One for Glenn Reservoir, which would provide storage of peak flows from the Sacramento River, would cost on the order of $110 per acre-foot. Los Vaqueros Reservoir in the northern San Joaquin Valley would cost about $295 per acre-foot. These costs are comparable with the cost to deliver reclaimed water to the major markets.

ALTERNATIVE FORMULATION AND EVALUATION

Conceptual engineering studies of alternative projects were carried out in parallel with marketing studies. The major markets are all to the east of the Bay Area, and geography dictates only three practical routes to the east from the Bay Area. The major routes selected were underwater through the Carquinez Straits or an adjacent shoreline route into the Delta, a route over Altamont Pass, or a southerly route through the Santa Clara Valley and east over Pacheco Pass.

A total of 16 typical projects were laid out and costs were estimated in order to arrive at a range of costs to provide water to the major markets. The 16 alternatives were then evaluated and four concepts were selected for more detailed consideration. These projects are shown on the attached figures and briefly summarized below.

MARKET/PROJECT CONCEPT NO. 1
Multipurpose in the Delta

Using a shoreline or underwater route into the Delta, this multipurpose project would provide water for management of Suisun Marsh, agricultural use in Solano County, and powerplant cooling at proposed new facilities of Pacific Gas and Electric.

One interesting aspect of this concept was that the water for management of Suisun Marsh would be required in the wintertime while agricultural use is heaviest in the summer. This reduces the storage required, since these are complementary uses. Depending on how these uses are combined, the total potential water use would be from 225,000-440,000 acre-feet per year. Costs would range from $145-$165 per acre-foot. (This is total annual cost including amortization of capital at 6-7/8 percent interest, a 50-year life for structures and 20-year replacement of mechanical equipment, energy costs at 3.28¢ per kilowatt hour and other operation and maintenance expenses.)

No allowance was included for "spin-off" projects along the alternative pipeline routes, but since either proposed route would pass major water-using industries (primarily oil refineries and powerplants), there would be excellent potential for spin-off projects if sufficient supply is available. The actual flow delivered to the project would depend on more detailed studies in Phase II which would also determine which wastewater agencies in the Bay Area would be connected to the recycling system.

MARKET/PROJECT CONCEPT NO. 2
Salinity Control in the Delta

The general concept in this alternative is to use reclaimed wastewater to make up a portion of the Delta outflow requirements of the State Department of Water Resources and the U.S. Bureau of Reclamation. The State Board Decision 1485 requires a minimum outflow of 3,300 cfs during dry years. About 10 percent of this could come from reclaimed water. Depending again on detailed evaluation of quantities required, quality affects, need for additional treatment, etc., the total flow could range from 225,000-440,000 acre-feet per year and the cost would range from $135-$145 per acre-foot.

More detailed studies are needed to assess the quality affects of this concept and also to determine whether the wastewater should be "discounted" up or down. That is, in order to maintain or exceed water quality objectives in the Delta, it might be necessary to somewhat increase the total Delta outflow, since reclaimed water would be of lower quality than Sacramento River quality, for example. Thus, if

100,000 acre-feet of reclaimed water is used for this purpose, it might "free up" 80,000 acre-feet of freshwater for other uses.

On the other hand, it may be that controlled release of reclaimed wastewater would be far more effective in salinity control than releases from upstream reservoirs and in fact reuse of 100,000 acre-feet of reclaimed water could make 120,000 acre-feet of freshwater available. At this point we simply don't know the answer to these questions. Detailed modeling studies will be required in Phase II to determine the impacts.

MARKET/PROJECT CONCEPT NO. 3
Agricultural Use in Northern San Joaquin Valley

Market studies in the northern San Joaquin Valley showed no interest in agricultural use, since farmers presently feel they have an ample supply of good quality water. However, to some extent this confidence is an illusion. There are presently areas of severe overdraft of ground water basins. That is, many farmers are "mining" ground water basins which are not being replenished.

This area is presently served by an existing conveyance, the Delta-Mendota Canal of the federal Central Valley Project. One possible means of providing service would be to blend, at approximately a 10:1 basis, freshwater and reclaimed water and provide this blended supply to agricultural users in the northern San Joaquin Valley. Additional treatment to ensure that the blended water would meet health requirements for "unrestricted agricultural use" might be required, since food chain crops are predominant in this area. The total usable flow could range from 250,000-440,000 acre-feet per year and with additional treatment of coagulation, sedimentation and filtration the cost would be on the order of $265-$310 per acre-foot.

If the blending alternative were selected, it would also be necessary to modify operations of the Central Valley Project so that there is no "cross connection" with the California State Water Project which provides drinking water to Southern California. This would require some modifications in operations of the Central Valley Project. In addition, those few communities which use the Central Valley Project as a source of domestic water supply would have to be provided with safe potable systems as a mitigation measure.

MARKET/PROJECT CONCEPT NO. 4
Agricultural Use in the Southern San Joaquin Valley

This was the most expensive alternative considered but it is also the best market from the standpoint of having "willing buyers." Farmers in the southern San Joaquin Valley generally grow fiber, fodder and seed crops (primarily cotton) and are badly in need of water. As an example, one of the major San Joaquin Valley irrigation districts presently has entitlements to only 1.8 acre-feet per acre and has annual demands of 2.5 acre-feet. Thus in dry years production is cut back. Since cotton is the predominant crop, no additional treatment would be required to meet health standards. Assuming 80 miles of new conveyance, the total potential use of reclaimed water would be 250,000-440,000 acre-feet per year and the cost would be $330-$340 per acre-foot. This alternative also has the largest energy requirements.

Costs for this alternative could be reduced if sharing of San Joaquin drainage facilities could be achieved.

CONCLUSIONS

In summary, Phase I of the San Francisco Bay Area Water Reuse Study has concluded the following:

1. The potential markets for reclaimed wastewater from the Bay Area far exceed the available supply. The total markets are on the order of 1.5 million acre-feet per year and only 440,000 is available.

2. There is no market for reclaimed water unless prices of reclaimed water are competitive with alternative supplies.

3. Costs for a large-scale reuse project at $130-$340 per acre-foot are comparable with new conventional supplies at $110-$295 per acre-foot.

At this point in Phase I, financing is the single greatest issue. For reclaimed water projects to be practical on a large scale, they must be compared on equal footing with development of additional conventional freshwater supplies through the construction of new dams. It appears that costs for either a large-scale reuse project or a new conventional supply are about the same. If the cost of either reclaimed water or a new dam is averaged in with the cost of existing water in the State Water Project and Central Valley Project, the results would be about the same, and the resulting costs appear reasonable. The price of water at the Delta is approximately $11 per acre-foot today. If a 440,000 acre-foot reclaimed water project were constructed, and this cost was averaged in with existing supplies, the result would be a $10 increase to a price of $21 per acre-foot. This assumes that the cost of new water is shared by all users of the State Water Project and/or Central Valley Project, as illustrated on Figure 3.

Other interesting conclusions from Phase I of the study are summarized below:

- In addition to financing and pricing there are a series of technical issues which must be resolved:
    - Feasibility of salinity control in the Delta using reclaimed water
    - Feasibility of blending and/or additional treatment to meet health standards for "unrestricted agricultural use"
    - Feasibility of using reclaimed water to maintain and enhance freshwater marshes
    - Resolution of salt balance and drainage problems in agricultural use areas
    - Legal and water rights issues
    - Institutional issues

- There is less wastewater available for regional reuse than was originally thought. This is due to the increased interest at the local level in reuse and the availability of grant funds for reuse projects.

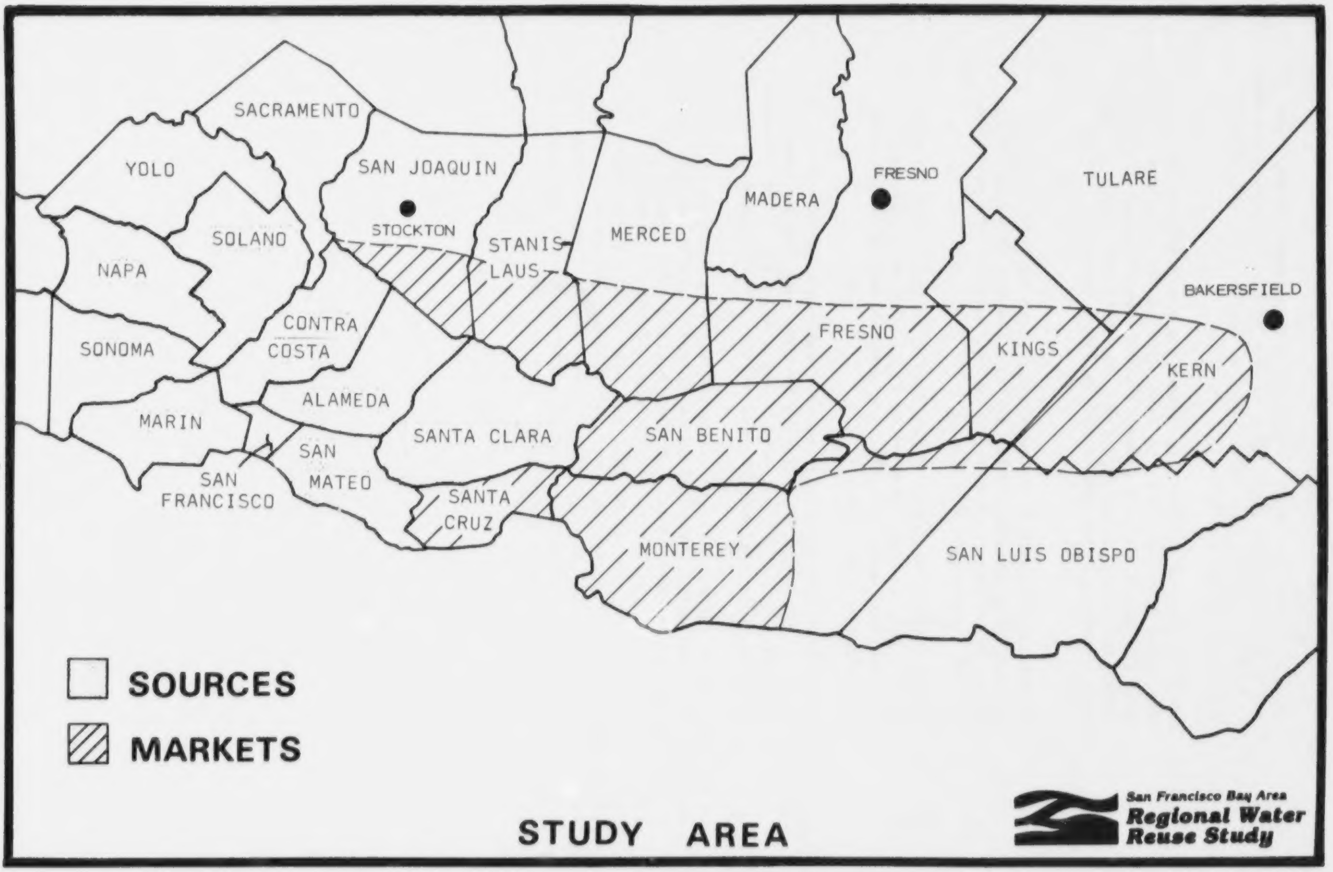
- Markets must be prioritized since the potential use of reclaimed water exceeds the available supply. In the regional study, higher priority was given to reuse projects where reclaimed water replaces a conventional supply rather than creating a new demand on the water resources of the state.

- It may be possible to serve agricultural markets in the southern San Joaquin Valley through sharing drainage facilities to be constructed to solve the salt balance problems of the San Joaquin Valley.

- Potable reuse need not be considered at this time. A more proper role of reclaimed water is to make available more conventional water supplies for potable use which requires the highest quality water.

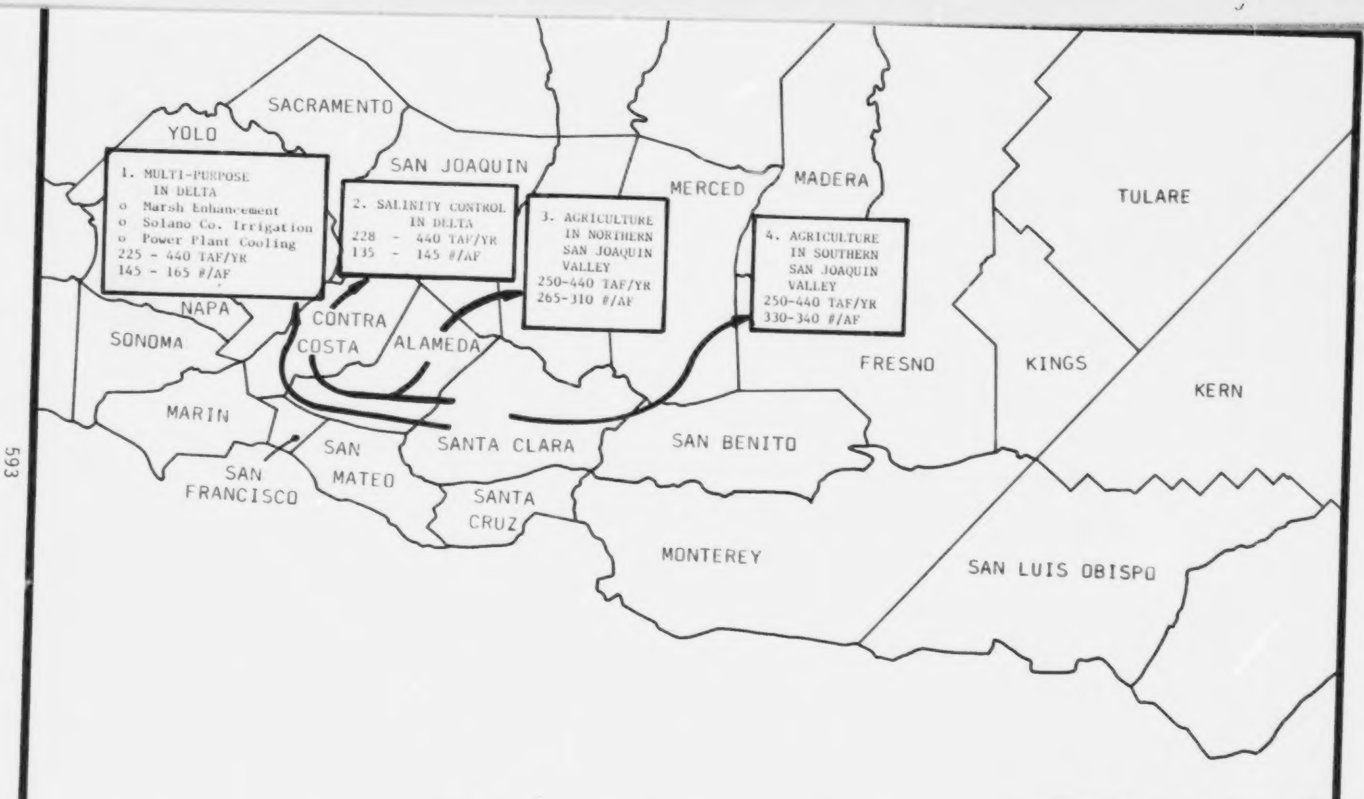
- The market for industrial process water is local, not regional in scope. Industrial process uses may be considered as spin-off projects along a pipeline route but will not justify a regional project in any of themselves.

In closing, while regional use of reclaimed water appears to be expensive compared with historical costs of water supply development, it is comparable with development of California's next conventional source of water supply. Due to environmental concerns about construction of new dams, it may be that the public will in essence demand maximum recycling before they will support construction of new dams in California. In short, although there are serious problems to overcome, indications are that reclaimed water may meet a significant part of California's future water needs.



STUDY AREA

FIGURE 1



MARKET PROJECT CONCEPTS

San Francisco Bay Area
Regional Water Reuse Study

FIGURE 2

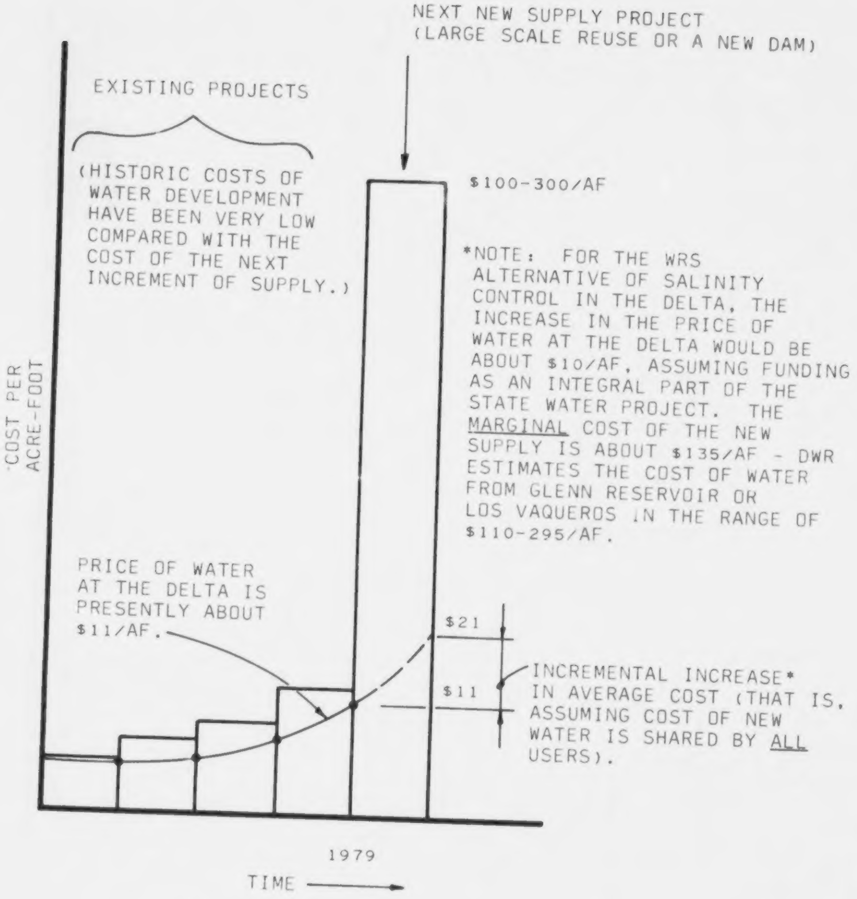


ILLUSTRATION OF
IMPACT OF NEW WATER DEVELOPMENT
COST ON STATE WATER PROJECT

FIGURE 3

San Francisco Bay Area
Regional Water Reuse Study

WASTEWATER REUSE ALTERNATIVES AT SOUTH LAKE TAHOE

Gordon Culp, Daniel Hinrichs,
Robert Williams, and Russell Culp
Culp/Wesner/Culp
El Dorado Hills, California

INTRODUCTION

The South Tahoe Public Utility District provides water and wastewater utility service to an area in California in the southern portion of the Lake Tahoe Basin (see Figure 1). The District has been a leader in the development and application of advanced wastewater treatment (AWT) techniques since the early 1960's (1-10). In accordance with a 1965 agreement between California and Nevada and with subsequently adopted California State law, the District has exported wastewater from the Tahoe Basin to Indian Creek Reservoir in Alpine County, California since 1968 when the current AWT plant and export pipeline were placed in service. The exported effluent has been used since 1968 as the primary water source for Indian Creek Reservoir (ICR) which was formed by dams on a normally dry tributary of Indian Creek. The reservoir supports a trout fishery and extensive camping facilities have been constructed around the reservoir for recreational use. In addition to this recreational reuse, a portion of the reservoir contents is used each summer by downstream farmers for irrigation of pasture and alfalfa.

A need for improved plant reliability and efficiency led to a recent evaluation of several reuse alternatives:

- Reuse of AWT effluent in the Lake Tahoe basin.
- Continued export of AWT effluent to ICR for recreational and agricultural reuse with increased efficiency of ammonia nitrogen control through nitrification or nitrogen removal.
- Export of secondary effluent to new storage reservoirs from which it would be drawn for agricultural reuse. ICR recreational use would be maintained by diversion of Carson River water into the reservoir.

This paper summarizes the results of this evaluation.

CURRENT TREATMENT SYSTEM

The existing wastewater treatment process consists of biological treatment, lime coagulation, settling, ammonia stripping, recarbonation, filtration, and carbon adsorption. The treatment capacity is 7.5 mgd (0.33 $m^3/3$). Furnaces for organic sludge incineration and lime recalcining are used. Treated wastewater is pumped from the plant 10 miles and lifted 265 feet to the Luther Pass Pump Station where there is a one million gallon storage reservoir for flow equalization and emergency storage. The Luther Pass Pumping Station lifts the effluent another 1,235 feet to the summit of Luther Pass through 6 miles of forcemain from where it flows through 11.8 miles of gravity line to Indian Creek Reservoir (165 acre surface area, 3,225 acre-feet of storage).

The current 30-day average requirements illustrate the nature of the treatment standards: bio-chemical oxygen demand (BOD) - 3 mg/l; methylene blue active substances (MBAS) - 0.5 mg/l; chemical oxygen demand (COD) - 20 mg/l; suspended solids (SS) - 1 mg/l; turbidity - 3 Jackson Units; pH - 7.0-7.5; and median coliform bacteria of less than 2 MPN/100 ml. Standards for Indian Creek Reservoir are: pH - average = 8.4, maximum = 8.6; ammonium + ammonia nitrogen - average = 4.0 mg/l, maximum = 6.0 mg/l; dissolved sulfide = 0.1 mg/l maximum; and dissolved oxygen = 5.0 mg/l minimum.

The plant met the treatment standards consistently from 1968 to 1975 with only minor, infrequent violations. A detailed analysis of plant performance during this period has been published (11). In 1975-1977, violations became more frequent and more significant. The most significant problem has been the difficulty in meeting the COD standards. A 50-80% increase in raw wastewater COD is a major factor and necessitates modification of the carbon adsorption portion of the AWT process if the current COD standards are continued. A recent study of Indian Creek Reservoir (12) has proposed that a COD standard of 30 mg/l would have no detrimental effect on water quality and the recreational use of the reservoir. Recently encountered problems in meeting other effluent standards appear to be primarily related to the loss of key experienced plant operating and supervisory personnel and deferred maintenance in 1975-1977. The plant removal of coliform bacteria has been consistently good over the last 10 years and has met standards. All 349 samples tested in 1975 were found to be free of coliform organisms - a record better than many water treatment plants. Virus testing has been limited but no virus has been found in the final effluent. Although there is no requirement for phosphorus removal, control of algal growths in Indian Creek Reservoir is dependent upon limiting the phosphorus discharged. Prior to 1975, phosphorus was typically reduced to less than 0.2 mg/l but concentrations of 0.4-0.8 mg/l have been common since that time due to poorer operational control. Increased algal productivity in Indian Creek Reservoir has occurred since 1975 due to higher phosphorus discharges.

Partial fish kills have occurred in Indian Creek Reservoir during some spring periods due to upward pH shifts and the presence of ammonium. Assured maintenance of satisfactory ammonium concentrations will require that the AWT process be modified so as to convert ammonium to the nitrate form or remove the nitrogen altogether by a process more reliable and economical than the current system.

POTENTIAL FOR IN-BASIN REUSE

Existing California State law requires waste export and prohibits in-basin reuse or disposal of wastewater, regardless of the degree of treatment provided. The intent of this law was to positively prevent any possible pollution of Lake Tahoe by wastewater. This goal has been accomplished.

Even at the time the law was being drafted, it was realized by all concerned that the Tahoe Basin was destined in time to become a water-short area. This has been emphasized by the 1977 drought. The State of Nevada has recently adopted a policy permitting wastewater reuse in the Nevada portion of the Tahoe Basin.

Assuming that an amendment to the Water Code could be obtained so as to permit reuse of wastewater effluent in the California portion of the Lake Tahoe Basin, probable waste discharge requirements proposed by the State for surface spreading or landscape irrigation in the Lake Tahoe Basin are:

Parameter	30-Day Mean	Maximum
COD	10 mg/l	20 mg/l
Total P	0.01 mg/l	0.02 mg.1
Total N	0.15 mg/l	0.30 mg/l
Turbidity	0.1 FTU	1.0 FTU
TFR	60 mg/l	90 mg/l
Cl	3 mg/l	4 mg/l
B	0.01 mg/l	---
SO_4	1.0 mg/l	2.0 mg/l
Total Coliform (MPN)	2.2/100 ml (7-day median)	23/100 ml
pH	7.0-7.5 (range)	
D.O.	90% of saturation (minimum) or 7 mg/l whichever is greater	

GENERAL REQUIREMENTS

Additional requirements would include:

- No direct discharge or return flow to any surface water
- Compliance with all water quality objectives applicable to waters of the Lake Tahoe Basin listed in Table 4-1 in Basin 6A Water Quality Control Plan

The prohibition on direct discharge to surface water would prohibit snow making as a potential reuse at this time, although the Regional Board could grant an exemption for such use in the future.

For groundwater injection, all requirements listed above would be applicable except the following:

Parameter	30-Day Mean	Maximum
COD	5 mg/l	10 mg/l

It is apparent that the above standards would require, in addition to the current AWT processes, the use of a demineralization process such as reverse osmosis. Even with reverse osmosis treatment, the ability to meet the proposed total nitrogen standard of 0.15-0.3 mg/l is questionable as well as those for B and SO_4. The State has indicated that standards consistent with the capability of reverse osmosis would probably prove acceptable.

Based on a preliminary analysis, an equivalent annual average flow of approximately 1.0 mgd is required for the irrigation of existing green areas. The remaining water could be used for groundwater recharge. This alternative would provide conservation of a vital resource in the South Tahoe Basin and eliminate the energy consumption for export pumping. The disadvantage is the cost for treatment when reverse osmosis is required.

Although the groundwater basin has the capacity to accept the entire wastewater flow, the political realities are such that the impact of in-basin reuse would first have to be demonstrated on a pilot scale. In 1978, the State legislature adopted legislation which would permit such a pilot demonstration. Thus, an alternative including a 1 mgd demonstration project to evaluate the practicability of in-basin reuse with the surplus effluent exported with the existing export system for agricultural reuse was evaluated in detail.

A need for 1 mgd fits very well for an introductory demonstration type of project. Such a volume of water treated by the existing South Tahoe process plus nitrogen removal and reverse osmosis could be used in summer for irrigation of grasslands and year-around for groundwater injection in a suitable groundwater area. This size project will allow an evaluation of the costs and acceptance of water recycled within the Tahoe Basin without risk to water quality in the Basin, since in-basin reuse could be interrupted at any time and all water exported if problems develop.

REUSE ALTERNATIVES EVALUATED

After initial evaluation of several alternatives, the following alternatives were selected for detailed evaluation:

Alternative 1 - Discharge of a nitrified effluent into Indian Creek Reservoir.

Alternative 2 - Remove nitrogen prior to discharge to Indian Creek Reservoir.

Alternative 3a - Agricultural reuse of secondary effluent in the Indian Creek area in the Carson River Basin in California by center pivot irrigation systems.

Alternative 3b - Agricultural reuse of secondary effluent by flood irrigation methods currently used by farmers in the Indian Creek area in the Carson River Basin in California.

Alternative 4 - Agricultural reuse of secondary effluent by flood irrigation in the Carson River Basin in California and a 1 mgd in-basin reuse demonstration project.

These alternatives were evaluated at maximum day design flows of 0.33, 0.44, and 0.66m^3/s (7.5, 10, and 15 mgd). These capacities represent, respectively, what would be associated with upgrading the plant at its current design capacity to meet the now-applicable reliability and treatment standards (some of which have been adopted since the 1968 design); the nominal federal construction grant-eligible capacity; and the capacity at the maximum potential development. For the purposes of this paper, the discussion will be primarily limited to a comparison of alternatives at 0.44m^3/s (10 mgd), the recommended capacity.

POTENTIAL IMPACTS OF WATER CONSERVATION PROGRAMS

Because of efforts to conserve water use during the 1977 drought, the District gained some experience with what the potential may be in this regard. Conservation of water by consumers can be practiced both inside and outside the dwelling. From the standpoint of a reduction in wastewater flow, however, it is only indoor conservation efforts which have an effect, and only indoor conservation will be discussed.

The District has already initiated a program to decrease indoor water usage. In early 1977, the District mailed to each household, a kit containing several water conservation devices. One device was a plastic bag, which when filled with water, sealed, and placed in the toilet flush tank, conserves a volume of water equal to its displacement, each time the toilet is flushed. Also enclosed were plastic washers which could be inserted into existing shower heads to reduce their rate of flow. Along with these devices, educational material on water conservation was also distributed.

The impact of the District's efforts was a 4.2 percent flow decrease for the first half of 1977, as compared to the first half of 1976.

A variety of concepts and practices have been implemented by other districts and agencies throughout both California and the United States. If implemented by the South Tahoe P.U.D., the potential for further reduction in wastewater flow exists. The concepts which could be utilized are:

- Complete metering of all water connections in the District
- Increase in water rates
- Mandatory use of water saving devices in any new construction or remodeling
- Mandatory water conservation

Each of these concepts is discussed individually in the following sections.

Complete Metering

Water service within the District is provided by District and three other independent water companies. None of these four purveyors has a completely metered system. A recent review of available literature indicates an initial reduction of as much as 30 percent in indoor usage can be experienced by converting from a flat rate charge to a metered charge. Over a period of time however, the savings are much less, and in time may reduce to nothing at all. Per capita water consumption is not unusually high under the flat rate system. Universal metering in areas under flat rates is always a highly controversial and emotional issue. Local residents undoubtedly would object strenuously to a suggestion that meters be installed. A carefully planned educational effort would be required to gain public acceptance.

One deterrent to universal metering is its very high cost. The South Tahoe P.U.D. estimates that it would cost about $3,000,000 to install meters on all its water services. The impacts of these costs could be mitigated somewhat by phasing the meter installation over a 10-15 year period. There would be additional costs for meters on private water company services operating in the District's boundaries. There are many higher priorities than metering in upgrading the water systems at the South Shore. For example, little or no fire protection is provided in many areas. Fire fighting capability would not only protect lives and property, but would also reduce fire insurance rates. As the high priority items are accomplished, a detailed study of water metering may be warranted.

Increase in Water Rates

Two methods of increasing the present water rate could be utilized to decrease water consumption. One is to simply increase rates, using the present rate structure, and another is to change the rate structure to an inverse rate structure. In an inverse rate structure, the charge per unit volume increases. Therefore, each increment utilized becomes progressively more expensive. Although effective, such approaches would undoubtedly meet with strong consumer resistance, and may not accomplish any greater reduction in usage than a well organized voluntary program.

Reduction in water use by raising water rates is dependent upon universal metering. Increasing flat rates accomplishes nothing toward water conservation.

Retrofit Devices in Existing Homes

Although the District has mailed retrofit devices to each home in the District, other types of devices are also available. Briefly, other devices which could be used, and the water savings which are possible are:

- Faucet flow controllers - Flow constriction devices can be placed in the line leading to kitchen and bathroom faucets. Such devices, assuming installation on all faucets, could save about 1 gpcd. Addition of faucet aerators will also reduce consumption by about 1 gpcd.
- Insulation of hot water lines - Depending upon the home and the hot water usage characteristics, use of insulation on hot water lines will reduce the waiting time for hot water, and could save as much as 1 to 2 gpcd.
- Toilet modifications - As contrasted with the plastic displacement bags mailed out by the District, which save about 1/2 gallon per flush, use of "toilet dams" work by actually blocking off portions of the toliet storage tank from use.

Mandatory Devices in New Construction

The principal water savings devices which could be made mandatory in all new construction are low flow shower heads and thermostatic mixing valves for showers. Low flow shower heads, which restrict flow similarly to shower head retrofit devices, could save up to 3 gpm during the shower. For a six minute shower every other day, this would amount to 9 gpcd, if everyone took showers rather than baths. The thermostatic mixing valve allows on-off operation, at a pre-set temperature, by simply pulling or pushing one knob. In theory, water can be saved by using water only at the start and end of the shower, and turning the water off during the middle of the shower when soap is being utilized. The amount of water which would be saved by using a thermostatic mixing valve and use of this showering technique is unknown. However, it is questionable whether many individuals would use this showering technique unless water rates were significantly increased.

Mandatory Water Conservation

Mandatory conservation could dramatically reduce outdoor consumption, but its impact upon indoor water usage would probably not be as great. At the same time, it may lead to somewhat less than desirable sanitary practices in the home. Mandatory conservation measures should not be considered unless a shortage occurs in the water supply itself.

Summary

Any attempt to add up the impact of all of the above measures is extremely difficult, and certainly open to considerable debate. However, the capability of additional reduction in wastewater flow due to indoor water conservation does exist. It is estimated that implementation of the above measures, except mandatory conservation, could result in a total reduction in per capita water usage of 10 to 15 percent during drought years. In wet years it will be difficult if not impossible to limit water use. Also, there is a real question as to whether water conservation can reduce water use by the large number of visitors to the Tahoe area on maximum days and at peak hours. It was concluded that it would be risky to reduce design wastewater flows in a heavily tourist-oriented area such as Tahoe until there is firm evidence that water conservation will reduce wastewater flows in wet weather and at critical times such as periods of peak tourist activity.

ALTERNATIVE 1, NITRIFICATION AND DISCHARGE TO ICR FOR RECREATIONAL AND AGRICULTURAL REUSE

This alternative includes the expansion and upgrading of the existing treatment plant to include flow equalization (utilizing the existing aeration basins) and biological nitrification utilizing the ABF process. After nitrification, the water is processed through chemical clarification, filtration and carbon adsorption facilities, and is then pumped to the 1 million gallon equalizing tank at Luther Pass. The Luther Pass pumping station withdraws treated effluent from the tank and boosts the water over Luther Pass for discharge to a new storage reservoir adjacent to the Indian Creek Reservoir (ICR). Overflow from the new reservoir or water from the transport pipeline is directed to Indian Creek Reservoir to maintain the proper pool levels. The water in ICR would continue to be used for recreation and irrigation as it is currently. This alternative would meet the existing treatment standards and would provide means for control of ammonia discharges to ICR. Construction costs for this alternative and all others are for expansion of the facility to 0.44m^3/s (10 mgd) capacity and are presented in terms of estimated mid-1980 costs (the projected mid-point of construction), reflect the higher than average construction costs at Lake Tahoe, and include a contingency allowance of 20%, engineering fees, legal fees, administrative costs, and interest during construction. The estimated costs are shown in Table 1.

O&M costs have been inflated to estimated 1981 levels, the first year of anticipated operation of the modified facilities. The average annual local costs over the 20 year period are .0388¢/l ($1.47/1,000 gallons). Fiscal year 1976 local costs for treatment and export were .0446¢/l ($1.69/1,000 gallons including $0.23 for existing bonds which are not included in the $1.47).

The annual primary energy (energy consumed by operation of the treatment and export facility) and secondary energy (energy required to manufacture chemicals used to treat the wastewater) for this alternative are shown in Table 2.

ALTERNATIVE 2, NITROGEN REMOVAL PRIOR TO DISCHARGE TO ICR FOR RECREATIONAL AND IRRIGATION USE

Another method of ammonia control is the total removal of nitrogen. This alternative includes the expansion and upgrading of the existing treatment plant to include flow equalization (utilizing the existing aeration basins) and biological secondary treatment using the ABF process. The secondary effluent is processed through chemical clarification, filtration, carbon adsorption and an ion exchange system for nitrogen removal and is then pumped to the 1 million gallon equalizing tank at Luther Pass. The Luther Pass pumping station draws water from the tank and boosts the water over Luther Pass for discharge to a new storage reservoir adjacent to Indian Creek Reservoir. Overflow from the new reservoir or water from the transport pipeline is directed to Indian Creek Reservoir to maintain the proper pool levels.

The estimated costs of Alternative 2 are shown in Table 3. The local annual costs average .0417¢/l ($1.58/1,000 gallons) over the 1981-2001 period. The annual resource consumption is shown in Table 4.

ALTERNATIVE 3, AGRICULTURAL REUSE OF SECONDARY EFFLUENT IN THE CARSON RIVER BASIN IN CALIFORNIA

This alternative includes the expansion and upgrading of certain processes of the existing plant while a majority of the existing AWT facilities will be taken out of service. The upgrading principally consists of flow equalization (utilizing the existing aeration basins) and biological treatment using the ABF process. The secondary effluent is disinfected and then pumped to the 1 million gallon equalizing tank at Luther Pass. The Luther Pass pumping station delivers the effluent to a new secondary effluent reservoir near ICR. In subalternate 3a, water from this reservoir would be used by area farmers to irrigate farmlands using center pivot irrigation systems. ICR water levels would be maintained by surface water supplies through the exchange of existing water rights held by the farmers in the basin. In subalternative 3b, the farmlands would be irrigated by flood irrigation methods, as is the current practice. This method requires capture and control of tailwaters from all irrigated lands. ICR water levels would be maintained as in 3a.

The irrigated areas involved in Alternate 3 are currently irrigated by private owners. The areas would be left in private ownership because of the fact that these areas constitute most of the privately owned land in Alpine County and any attempt by the District to purchase the property would cause major implementation problems. Long term (20 years or more) contracts would be made with the farmers. In Alternative 3a, the farmers would be responsible for the local share of the capital and for the O&M costs for the center pivot irrigation equipment. In Alternative 3b, effluent from the new reservoir would be discharged to the existing surface irrigation system. Several alternatives for surface irrigation were studied with the most feasible involving secondary effluent storage reservoirs on property adjacent to ICR. Tailwater from the irrigated area would be collected and pumped into an existing irrigation ditch, eliminating tailwater runoff to Indian Creek. Water rights exchanges would permit Carson River water to be diverted as necessary to Indian Creek to maintain downstream irrigation uses. These uses are normally supplied by runoff from the areas to be irrigated with secondary effluent. Tailwater controls would eliminate this runoff from areas irrigated with secondary effluent.

The estimated costs of Alternative 3 are shown in Table 5. The local annual costs over the 1981-2001 period are .0238¢/1 ($0.90/1,000 gallons) for 3a and .0232¢/1 ($0.88/1,000 gallons) for 3b. These costs are based on the use of wells to control seepage from the secondary effluent storage reservoirs. If lining of the reservoirs is required, the capital costs would increase by about $4,500,000 for Alternative 3b and $2,500,000 for Alternative 3a. The annual resource consumption is shown in Table 6.

The simplicity of the process used at the treatment plant, the long detention times of several months in the new secondary effluent reservoir, and the effective treatment provided by passing the effluent through the soil combine to provide a very high degree of treatment reliability for this alternative.

ALTERNATIVE 4, AGRICULTURAL REUSE OF SECONDARY EFFLUENT IN THE CARSON RIVER BASIN IN CALIFORNIA AND A 1 MGD REUSE DEMONSTRATION PROJECT IN THE LAKE TAHOE BASIN

In addition to the flood irrigation system of Alternative 3b, a one million gallon per day (1 mgd) AWT plant is included for demonstration of in-basin reuse as discussed earlier. The 1 mgd demonstration process consists of chemical clarification, filtration, carbon adsorption, selective ion exchange and reverse osmosis to treat the wastewater to a quality approximately equivalent to that of Lake Tahoe.

Suggestions have been made that such a demonstration project be conducted outside the South Tahoe basin. However, because prevailing conditions such as climate, topography, soils, vegetation and other factors having a direct bearing on in-basin reuse are unique to the South Tahoe Basin, it is not practical or even wise, to transfer data obtained from pilot or demonstration plants outside the basin, to project results of an in-basin system. Even with extensive tests at a location of similar environment outside the basin, demonstration of plant operations in the South Tahoe basin will still be needed before recommending an implementation schedule of treatment quality and uses. Also, out-of-basin data are already available for all the proposed treatment processes and uses, through many existing operations, but the results, although helpful, are not directly transferable. Based on these comments, the in-basin reuse demonstration project was made a part of Alternative 4.

The reclaimed wastewater would be used for golf course and green belt irrigation during the summer months and groundwater recharge during the winter months. A nominal amount of snow making could also be included during the winter months as a test for full scale use. The in-basin reuse would be monitored continuously and the results evaluated and reported to determine the feasibility of in-basin reuse as a long-term wastewater management approach. The estimated costs of Alternative 4 are shown in Table 7.

The local annual costs average .0325¢/l ($1.23/1,000 gallons) over the 1981-2001 period.

The annual resource consumption is shown in Table 8.

COMPARISON OF ALTERNATIVES

Table 9 summarizes the relative costs and energy consumption of the four alternatives.

In addition, the cost of in-basin reuse of all District wastewater flows in excess of the capacity of the existing export system (8 mgd) was also estimated. Such in-basin reuse would serve many useful purposes such as: reduce the export of water from the basin which would lessen the potential impact of water use in the District on the Lake Tahoe water rights now awaiting adjudication; provide improved overall water management in the South Lake Tahoe Basin; eliminate the requirement for expanding the export pipeline; lessen the energy consumption for wastewater pumping over Luther Pass; demonstrate that the District's long-term goal of in-basin reuse is viable and not detrimental to the environment; and apply the knowledge gained in ten years of operation of Indian Creek Reservoir to further beneficial uses. The District's original commitment to in-basin reuse for the long term solution to wastewater treatment and an overall improvement of the water resources management in the basin originally led to the construction and operation of Indian Creek Reservoir.

The treatment systems considered in the analysis of in-basin reuse of all wastewater flows above the capacity of the existing export system included the following processes, after secondary treatment:

- In-Basin System A - Chemical clarification, filtration, upflow-downflow carbon, selective ion exchange and reverse osmosis (same system as would be demonstrated in Alternate 4).
- In-Basin System B - Chemical clarification, filtration, upflow-downflow carbon and selective ion exchange (would provide very high removals of phosphorus, nitrogen and organics).
- In-Basin System C - Chemical clarification, filtration, reverse osmosis, and upflow-downflow carbon (would also provide dissolved solids control and further removals of nitrogen, phosphorus, and organics).

The following economic evaluation of systems for treatment of the entire wastewater flow resulted:

Alt.		Present Worth ($1,000)
3bl	Secondary Treatment, Export, Flood Irrigation	32,940
-	In-basin System B (chemical treatment, ion exchange, carbon)	39,690
-	In-basin System C (chemical treatment, carbon, reverse osmosis)	42,537
1	Export Nitrified AWT Effluent	45,406
-	In-basin System A (chemical treatment, carbon, ion exchange, reverse osmosis)	47,952
2	Provide Nitrogen Removal (ion exchange) prior to export	51,383

For all the alternatives, an analysis for a 20-year planning period to the year 2001 was considered. An assumption as to the desirable capacity of the wastewater transport system to Indian Creek Reservoir was fixed at 8 mgd. The actual capacity of the system has been determined to be in the range of 9 to 10 mgd. Assuming the reuse plant would treat all flows above the capacity of the export line, selection of the lower transport capacity yields a somewhat conservative analysis in that a slightly larger reuse plant would be constructed and operated.

The above economic comparison does not reflect some of the value of beneficial factors which are associated with the in-basin reuse systems. One potential factor is the limitation on water use within the Tahoe Basin and the value that may be placed on the water rights. Inclusion of a value for the water used for in-basin reuse may also be sufficient to equalize the costs. The value placed on this water, however, is subjective, unless a history of water rights sales are recorded.

Alpine County (the county in which secondary effluent irrigation would be practiced) has not been receptive to past proposals similar to Alternative 3bl. If Alternative 3bl cannot be implemented, then in-basin reuse still would not be competitive with export of nitrified effluent (Alternative 1) if ion exchange and reverse osmosis are required (in-basin system A). However, in-basin systems B and C would both be lower in cost than Alternative 1. Thus in-basin reuse does have some potential long term economic benefits as well as in-basin resource conservation.

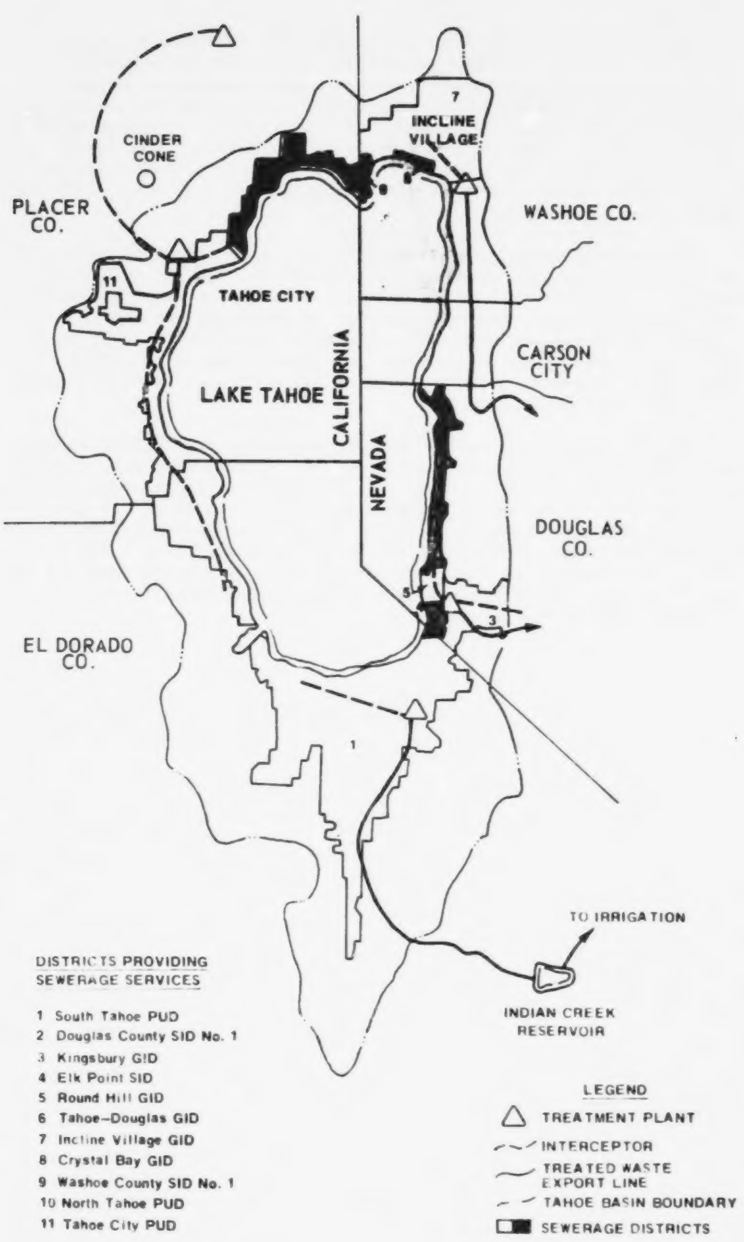


Figure 1. Location of South Tahoe Public Utility District

TABLE 1
Summary of Costs, Alternative 1
(0.44m^3/sec (10 mgd) capacity)

Treatment			Present Worth Of All Costs, 1981-2001
Capital Costs	$25,276,500		$18,539,100
O&M Costs (annual)	2,569,300		18,500,300
		Subtotal	$37,039,400
Effluent Transport			
Capital Costs	$ 1,325,000		$ 2,891,700
O&M Costs (annual)	667,200		4,631,900
		Subtotal	$ 7,523,600
Effluent Storage			
Capital Costs	$ 536,600		$ 738,800
O&M Costs (annual)	14,000		103,900
		Subtotal	$ 842,700
		Total	$45,405,700

TABLE 2
Summary of Annual Energy Requirements, Alternative 1
(0.44m^3/s (10 mgd) capacity)

	Energy 1,000 kwh	Fuel 10^6 Btu
Primary, on-site energy	25,412	89,244
Secondary, off-site energy	1,655	16,637
TOTAL	27,067	105,881

TABLE 3
Summary of Costs, Alternative 2
(0.44m^3/sec (10 mgd) capacity)

Treatment		Present Worth Of All Costs, 1981-2001
Capital Costs	$32,222,900	$23,949,000
O&M Costs (annual)	2,655,200	19,576,600
		$43,526,600
Effluent Transport		
Capital Costs	$ 1,325,000	$2,891,700
O&M Costs (annual)	667,200	$4,631,900
		$7,523,600
Effluent Storage		
Capital Costs	536,600	$ 738,800
O&M Costs (annual)	14,000	103,900
	Subtotal	$ 842,700
	Total	$51,892,900

TABLE 4
Summary of Annual Energy Requirements, Alternative 2
(0.44m^3/sec (10 mgd) capacity)

	Energy 1,000 kwh	Fuel 10^6 Btu
Primary, on-site energy	25,320	91,320
Secondary, off-site energy	3,503	35,578
TOTAL	29,344	126,898

TABLE 5
Summary of Costs, Alternatives 3a and 3b
($0.44 m^3$/sec (10 mgd) capacity)

Treatment		Present Worth Of All Costs, 1981-2001
Alternative 3a		
Capital Costs	$28,650,100	$20,929,900
O&M Costs (annual)	1,487,300	10,513,500
		$31,443,400
Alternative 3b		
Capital Costs	$20,184,500	$15,255,900
O&M Costs (annual)	1,421,300	10,188,400
		$25,414,300
Effluent Transport		
Capital Costs	$ 1,536,500	$ 2,891,700
O&M Costs (annual)	667,200	4,631,900
	Subtotal	$ 7,523,600
	Total 3a	$38,967,000
	Total 3b	$32,937,900

TABLE 6
Summary of Annual Energy Requirements, Alternatives 3a and 3b
($0.44 m^3$/s (10 mgd) capacity)

	Energy 1,000 kwh	Fuel 10^6 Btu
Alternative 3a		
Primary, on-site energy	21,482	35,380
Secondary, off-site energy	369	3,916
TOTAL	21,851	39,296
Alternative 3b		
Primary, on-site energy	21,281	35,380
Secondary, off-site energy	369	3,916
TOTAL	21,650	39,296

TABLE 7
Summary of Costs, Alternative 4
($0.44 m^3$/sec (10 mgd) capacity)

Treatment		Present Worth Of All Costs, 1981-2001
Capital Costs	$25,238,400	$18,691,200
O&M Costs (annual)	2,297,800	16,423,600
		$35,114,800
Effluent Transport		
Capital Costs	$ 1,325,000	$ 2,891,700
O&M Costs (annual)	569,500	3,924,200
	Subtotal	$ 6,815,900
	Total	$41,930,700

TABLE 8
Summary of Annual Energy Requirements, Alternative 4
($0.44 m^3$/s (10 mgd) capacity)

	Energy 1,000 kwh	Fuel 10^6 Btu
Primary, on-site energy	22,446	33,139
Secondary, off-site energy	1,489	15,124
TOTAL	23,935	48,263

TABLE 9
Comparative Summary

Alt.		Present Worth ($1,000)	Average Local Costs, $/1,000 gals	Annual Energy Requirements On-Site kwhx10^3	Annual Energy Requirements On-Site Btux10^6	Annual Energy Requirements Off-Site kwhx10^3	Annual Energy Requirements Off-Site Btux10^6
3b1	Secondary Treatment, Flood Irrigation	32,940	0.88	21,281	35,380	369	3,916
4	Above Alternative Plus 1 mgd In-Basin Demonstration of Reuse of AWT Effluent (Includes Reverse Osmosis)	41,931	1.28	22,446	33,139	1,489	15,124
1	Export Nitrified AWT Effluent	45,406	1.47	25,412	89,244	1,655	16,637
2	Provide Nitrogen Removal (Selective Ion Exchange) Prior to Export	51,383	1.58	25,320	91,320	3,503	35,578

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THE EXPERIMENTAL ESTUARY WATER TREATMENT PLANT

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The use of the Potomac River estuary as a possible water supply source for the Metropolitan Washington Area is one of several alternatives discussed in the Corps of Engineers Northeastern United States Water Supply Study (NEWS).[1] In 1974 the Congress authorized the construction of an experimental estuary water treatment plant (EEWTP) which could be used to investigate the feasibility of this alternative. The design for this experimental plant was completed for the Corps by Malcolm Pirnie, Inc. in 1977.[2] Construction of the plant should be completed by the fall of 1979. The operation of the experimental treatment plant is scheduled for a two-year period beginning in March of 1980. A six-month predemonstration operating period beginning about September 1979 will precede the actual operation for comparative evaluation purposes.

To fully comprehend the scope of the testing and evaluation program (T & E Program) an understanding and appreciation of the design of the experimental plant and the flexibility inherent in its operation is considered useful. Most process units in the plant have been provided in duplicate, some of which can be operated in both series and parallel, and most of which can be bypassed if desired. A side stream with flows up to 10,000 gpd allows the testing and evaluation of special or unique processes for short periods of time. A blending tank allows the mixing of a raw water quality to any specification. A full description of the specific design parameters and operation elements of the experimental plant is presented in the text of this paper.

The development of the T & E Program for the EEWTP was somewhat complicated by a number of factors. These included: the unique circumstances associated with its location; the uncertainties associated with treatment of a recycled water from the estuary during periods of low flow in the river; the current concern about contaminants for which no recognized standards exist relative to their concentration in drinking water; the problem of determining what quality of raw water to treat in the plant; the decision on how to deal with the many potential variables, internal and external, to the operation of the plant; and, the need to produce scientifically acceptable data and results for evaluative purposes. This paper discusses all of these factors and their resolution during the development of the T & E Program.

DESCRIPTION OF THE EXPERIMENTAL ESTUARY WATER TREATMENT PLANT

The Experimental Estuary Water Treatment Plant was designed to provide a capability of using in various modes the off-the-shelf unit processes available for treating a raw water supply of questionable and unknown quality to produce a potable water of acceptable quality. It required consideration of all facilities from the intake structure to the final clearwell. It required a capability to blend waters to some future predicted raw water composition. It required a capability to provide both series and parallel flow for different unit processes provided to accomplish the same purpose. Process units were considered to be "off-the-shelf" items if they were used extensively for water treatment purposes even though they may not be routinely used in design practice in this country or under the express circumstances conveyed by the circumstances of this project. A system capable of handling a flow of 1 mgd was the primary design parameter affecting all unit processes. The preliminary design and basic unit sizing was presented in the Design Memorandum prepared by Malcolm Pirnie, Inc. in 1976.[3] A description of specific design and operational elements of each of the units available for use in this experimental treatment plant is found in the succeeding paragraphs.

Input Facilities

In order to provide an inflow of raw water to the blending tank an estuary pumping station as well as a pumping station to provide secondary effluent from the District of Columbia WWTP was required. The estuary pumping station has two 0.5 mgd constant speed centrifugal pumps and a 12-inch submerged suction pipe. The intake is located approximately 1000 feet from the shoreline and approximately one-half mile above the Blue Plains Wastewater outfall. The intake structure consists of a bar screen with a 1/4" x 1/4" wire mesh welded behind the bars. A flow meter with remote indicator/recorder and a flow control valve with manual adjust capability are provided in the discharge main at the pilot plant. The flow from the estuary can then be varied up to a maximum of 1.0 mgd.

The pumping station for taking effluent from the Blue Plains wastewater treatment plant is located above the influent forebays of the new multimedia filtration facility. Two 0.5 mgd constant speed vertical turbine pumps are located in each of the two forebays. Two pumps were located in each forebay because it is possible that one or the other forebay may not be in use. An 8-inch diameter force main transports the effluent from the pumping station, approximately 3500 feet to the pilot plant. A flow meter and control valve are provided in the discharge main at the pilot plant. The system for pumping secondary effluent is designed for a maximum flow of 1.0 mgd.

Basic Treatment Train

The basic treatment train was designed to handle a maximum flow of 1.0 mgd and consists of microscreening, ammonia removal, aeration, rapid mix, flocculation, sedimentation, filtration, activated carbon adsorption and disinfection. A flow schematic of the possible unit treatment processes is shown in Figure 1.

Two microscreen units have been provided for the removal of organic detritus, suspended solids and micro-organisms associated with the Potomac Estuary water and the secondary effluent. The microscreens are constructed of 35 micron stainless steel mesh and each is designed for a maximum flow of 1.0 mgd. The rotating screen will be backwashed continuously with water from the microscreen effluent chamber. The rotating speed of the screens as well as the quantity of backwash water is controlled automatically based on head loss through the microscreens. The captured solids flow by gravity from the waste collection hopper to the sludge thickener.

A selective ion exchange process is utilized to reduce the concentration of ammonia in the Blue Plains secondary effluent to approximately 1 mg/l. Following passage through the microscreen, the secondary effluent will be pumped through the two ion exchange units. Each unit was designed for a maximum hydraulic flow of 0.5 mgd and contains a natural zeolite (clinoptilolite) media which has a relatively high affinity for ammonia ions. The ion exchange units are 7-foot in diameter and each contains approximately 155 cubic feet of media. Backwashing/regeneration is scheduled to be initiated when the concentration of ammonia reaches approximately 2 mg/l or when suspended solids buildup causes head losses to exceed 10 psi. The regeneration cycle consists of a 15-minute backwash period at a rate of about 8 gpm/sf, a 2.5-hour regeneration period and then a 5-minute rinse to remove excess regenerate from the bed. The regenerate solution is 1.6 percent sodium chloride with sufficient caustic soda to raise the pH to approximately 10. The regenerate solution will be fed upward through the units at a rate of 100 gpm. The spent backwash water will be discharged to the sludge thickener. The spent regenerate solution and rinse water will be discharged to the raw sewage conduit.

The blend tank is provided to function as a receiving and mixing basin for the two raw water sources. Facilities are also provided at this point for the addition of dissolved solids and treated potable municipal water. With these capabilities the input water to the subsequent treatment process can be blended to simulate any projected future water quality.

The aeration process serves to oxidize iron, manganese and some organic matter, and to increase the palatability of the water by the removal of objectionable gases and other taste and odor producing substances. The square aeration tank will be equipped with a turbine-type aerator and will provide a detention time of approximately 10-minutes.

The rapid mix facilities involves a two-stage tank for dispersement of the coagulants into the raw water. The detention time in the tank will be approximately one-minute at the maximum flow of 1.0 mgd. Each compartment will contain a turbine mixer with a mixing "G" coefficient of 700 sec^{-1}. The two-stage flocculation basin was sized for a total detention time of 20-minutes at the maximum design flow of 1.0 mgd. Each compartment of the flocculation basin is equipped with two turbine-type mixers with variable speed motors. The first compartment will provide a mixing "G" coefficient of 100 $sec.^{-1}$ and the second a "G" coefficient of 50 $sec.^{-1}$. The speed of the flocculators will be manually controlled.

The flocculated water will pass through 36 four-inch orifices (9 across x 4 down) in the baffle wall into a rectangular settling basin. The basin provides a 2-hour detention with a corresponding surface settling rate of about 1200 gpd per square foot of surface area. A continuously operating sludge scrapper system moves the settled solids to sludge hoppers at the influent end of the basin. From there, the sludge is pumped to the gravity sludge thickener. The sludge pumps are controlled automatically by time clock and sludge density. A skimmer collects any floating material and discharges them to a dewatering trap.

The clarified water will discharge to two effluent troughs through submerged orifices to the predisinfection tanks or directly to the rapid filters. The predisinfection tank was designed for a detention time of approximately 5-minutes and can accommodate either chlorine or ozone. When the lime coagulation mode is being used the clarified water will be passed through a recarbonation tank before predisinfection and filtration.

The filtration process involves two dual media filters consisting of anthracite coal and silica sand. The filters are 30-inches deep and rest on a 10-inch layer of silica gravel. The anthracite coal (specific gravity 1.5, effective size 1.0 mm ± 0.2 mm) has a depth of 22-inches, and the remaining silica sand (specific gravity 2.6, effective size 0.45 mm ± 0.1 mm, and uniformity coefficient of less than 1.3) has a depth of 8-inches. The filter bottom is precast Wheeler Bottom Blocks on concrete piers.

The filtration loading rate was designed at 6 gpm per square foot at the maximum flow of 1 mgd. Filter controls are located adjacent to the filters. The control console contains indicators for effluent turbidity, loss-of-head, filter-clearwell level, and backwash holding tank level. The turbidity will be monitored continuously and indicated and recorded in the central operations room. An alarm system has been provided to indicate high effluent turbidity and loss-of-head.

Backwashing of the filters is initiated manually with subsequent automatic sequencing of valves and pumps. The backwash pumps were designed to provide backwash water at a rate of from 15 to 23 gpm per square foot. The rate is maintained by a flow control valve which can be manually adjusted to the desired rate. The surface wash pumps were designed to provide a flow of 1 gpm per square foot via the 5-foot diameter surface agitators.

Following rapid sand filtration, the water is treated by an adsorption system for the removal of dissolved organic substances. The process consists of 3 upflow columns and 3 pressure downflow columns, each containing granular activated carbon. When the adsorptive capacity of the carbon is exhausted, the carbon will be replaced by means of an eductor system. Spent carbon will be regenerated off-site. Both upflow and downflow units were specified to allow comparison of the operating efficiencies of the two unit types. The columns can be operated in two parallel trains or in series, e.g., upflow followed by downflow.

The columns were designed for a maximum hydraulic loading of 9 gpm per square foot with a corresponding detention time of approximately 7.5 minutes per unit. They have a diameter of approximately 7 feet and an overall height of about 17 feet. The carbon beds are approximately 9 feet deep in each column. The granular activated carbon which was specified is an 8 x 30 mesh (maximum 8 percent retained on No. 8 sieve, maximum 5 percent passing No. 30 sieve).

Backwash requirements were based on a rate of 20 gpm per square foot. This rate ensures expansion of the carbon bed by approximately 50 percent. Each column will be backwashed for a period of 15-minutes. During the first 5-minutes of this period, the upflow columns will be air washed at the rate of 3 SCFM per square foot. The downflow columns will be surface washed. A manual control system is provided to operate the columns. Each column is equipped with rate-of-flow controllers and pressure gages. Exhaustion of the adsorptive capacity of the carbon beds will be monitored by a TOC analyzer using samples from the effluent of each column.

Because of the nature of the raw water source for the pilot plant, the disinfection process will be a critical function. Facilities were provided for both pre- and postdisinfection. Predisinfection can take place prior to filtration or be bypassed if it is not necessary. The product water from the carbon columns will receive postdisinfection. Separate disinfection facilities were also provided for the "side stream" which has passed through the dissolved solids removal facilities. In order to evaluate the effectiveness of other disinfection processes, facilities were provided for both chlorination and ozonation at the predisinfection location, and facilities were provided for chlorination, ozonation, and ultraviolet irradiation for postdisinfection of both the main stream and the side stream. The postdisinfection facilities are arranged so that any two of the three processes may be operated in parallel with each other. In addition, the ozonation and ultraviolet processes can be followed by chlorination.

The chlorine facilities include a two-bay contact tank which will provide a contact time of approximately 65-minutes at 0.5 mgd and 32-minutes at 1.0 mgd. By using only one bay of the tank, these detention times can be cut in half. The gas-type chlorinators have a capacity range of from 5 to 140 lbs per day and will be automatically controlled by the chlorine residual analyzer/recorder with control loop. One-hundred fifty lb chlorine gas cylinders will be used with a 2-cylinder scale.

The ozone contact tank has two compartments and will provide a contact time of approximately 24-minutes at 0.5 mgd and 12-minutes at 1.0 mgd, when both chambers are utilized. Horizontal baffles form an over/under serpentine flow to reduce short circuiting and enhance ozone transfer. The ozone will be produced by a single water cooled generator using ambiant room air as its input. The generator has a maximum capacity of approximately 83 lbs per day and will supply both post ozonation as well as preozonation, when it is used. A rotometer and manual control valve regulates the quantity of ozone flowing to the predisinfection tank. The feed rate for postozonation can be controlled manually or automatically by the ozone analyzer/controller.

The ultraviolet irradiation equipment consists of a multitube, self-contained unit, with a maximum hydraulic capacity of 0.5 mgd. The unit was designed to maintain a dosage rate of 33,000 MW sec/cm^2 (Ultrads).

Side Stream Processes

A side stream flow has been provided from the carbon column clearwell, but before postdisinfection, to evaluate the effectiveness of various unit processes in removing dissolved solids. The processes to be evaluated will be reverse osmosis, electrodialysis and ion exchange. Only one process will be operated at a time and each will be designed for a flow rate of 10,000 gpd. The removal of dissolved solids is being investigated in the event the future TDS concentration in the estuary exceeds recommended drinking water limits.

Design of the reverse osmosis unit was based on production of 75-percent product and 25-percent waste concentrate flow. The permeable membranes are the spiral wound type made of cellulose acetate material. A cartridge type 10-micron polypropylene filter is located upstream of the feed pump to remove carbon fines and other large particulates. An acid feed system is included to prevent membrane fouling by periodically flushing the units with a weak acid solution.

The electrodialysis process consists of two stacks. Each stack has two electrical and six hydraulic stages. The cell pairs within the stages consists of a cation and anion permeable membrane. The membrane cells have a styrene base polymer cross-lined with divinyl benzene material. A product water recovery of 80-percent with a dissolved solids removal of 85-percent is anticipated. A cartridge type 10-micron polypropylene filter is provided for the removal of particulate matter. The self-contained unit includes a local control panel with high pressure and high dissolved solids concentration alarms.

The ion exchange process consists of two fixed-bed pressure units. The influent water will pass through the cation exchange vessel first where metallic cations are removed (exchanging places with H^+ ions of the resin). The resulting acid solution will then pass through the anion exchanger where anions are removed (exchanging places with OH^- ions of the resin). The cation resin will be regenerated with sulfuric acid and the anion resin with sodium hydroxide. Each exchanger will be backwashed for approximately 10-minutes at a flow of about 5 gpm per square foot prior to regeneration. The regeneration will be initiated manually with subsequent automatic sequencing. It is anticipated that no more than two regenerations will be required per day.

Chemical Recovery System

A recovery system was designed to enable the evaluation of the operating results and coagulation characteristics of recovered and recycled coagulants. The sludge handling system was sized to enable operation of the chemical recovery system for either the alum or magnesium bicarbonate-lime mode. Each mode will be used separately over a predetermined period of operation. In the alum mode, the thickened sludge will be dosed with sulfuric acid to dissolve the aluminum hydroxide floc into a soluble aluminum sulfate, which is recovered by a decant procedure. The remaining sludge will be dewatered in a centrifuge and disposed of in a sanitary landfill.

When operating under the magnesium bicarbonate-lime mode, the thickened sludge is mixed with carbon dioxide gas that has been recovered from the multiple hearth furnace. The addition of carbon dioxide causes the magnesium hydroxide precipitate to be solubilized into magnesium bicarbonate. The sludge is pumped to a classifying centrifuge which dewaters the sludge into a cake containing 40-percent dry solids. The sludge cake, containing most of the calcium carbonate and suspended solids, is conveyed to the furnace for recalcination. The magnesium bicarbonate centrate is then pumped to a clarifying centrifuge and then to a storage tank for reuse. The residual sludge cake from the clarifying centrifuge will be disposed of in a sanitary landfill.

The chemical recovery system is designed for conditions resulting from a maximum plant production of 1.0 mgd. Continuous or batch recovery operations can be used depending on the chemical feed mode. In order to keep the sludge handling equipment operating at approximately the same rate in both modes, the alum recovery process can operate once a day over a 16-hour period to allow for decanting and dewatering. The purity of alum recovered will depend on the degree of effectiveness of the decant method. Approximately 2000 gpd of alum solution can be recovered for use with supplemental commercial alum, as required, for the feed system.

In the magnesium bicarbonate-lime mode, at a plant flow of 1.0 mgd, the recovery system will be operated on a continuous basis. The sludge is pumped from the thickener to the sludge carbonation tanks where the magnesium hydroxide is solubilized into magnesium bicarbonate and then pumped to the classifying centrifuge, from which approximately 3900 lb per day of 40-percent dry solids is conveyed to the furnace for recalcination.

The chemical recovery system is under manual control with controls either located at the equipment or at a control panel in the area. The feeding of carbon dioxide, acid, and lime to adjust pH is controlled automatically based on a preset pH value.

DEVELOPMENT OF THE TESTING AND EVALUATION PROGRAM

Objectives and Methods

The objective of the operation of the experimental estuary water treatment plant is to determine the feasibility of producing potable water from the Potomac River estuary. Inherent in such a feasibility study is an evaluation of the performance of the system as a whole, and an evaluation of the reliability, stability and consistency of the unit processes, for producing an acceptable finished water quality. To reach this objective development of the testing and evaluation program was focused on three areas: 1) determination of the quality of the input water to be treated; 2) identification of the processes to treat the water, and determination of the effectiveness of these processes; and 3) evaluation of the quality of the water produced by the experimental plant.

A baseline water quality evaluation program was undertaken by the Corps of Engineers. Water samples were routinely collected and analyzed from various points in the estuary, both above and below the proposed intake to the pilot plant. This monitoring program provided some of the information used in the modeling studies that were undertaken.

The firm of GKY and Associates of McLean, Virginia was retained to review existing modeling information, construct an estuary water quality model and perform the modeling studies required for this project. Water quality modeling studies were conducted to achieve two objectives: 1) enable the prediction of variability in selected water quality parameters associated with changes and as a basis for developing a time series model; and, 2) enable the prediction of TDS and other water quality parameters at a future intake point and under various flow conditions. The water quality fluctuations in the Potomac River estuary at the intake of the experimental plant was an important consideration in the design of the experiments that evaluate the performance of the pilot plant. The prediction of the future water quality (year 2030) responds to the concern that high levels of estuary water use may cause salinity build-up from cycling of water through the regional water treatment systems and from migration of salt water upstream when fresh water flows are reduced.

Certain criteria were considered as essential to be met in the selection of the treatment process to be used in the conduct of this study. These were:

- That the basic treatment process represent a proven technique for treatment of average raw water supplies.

- That modifications to the basic process be generally accepted for the purposes to which they will be put.

- That a single (at the most two) treatment configuration be used to produce data which on evaluation would be a valid basis for determining if the objective of the study project has been met.

The selection of the initial process train reflected a desire to operate the experimental water treatment plant during the first year so that the only variations to be encountered would be due to changes in the plant influent arising from causes external to the plant, and also to enable evaluation of the use of parallel upflow and downflow carbon adsorption systems. Modifications to the process train and factors to be investigated during the second year will depend on the results obtained in the first year.

An important next step was a determination of what data to collect, where the data should be collected, and at what frequency. To enhance acceptance of the data we developed a statistical analysis approach, which would provide the basis for deciding when enough data had been collected to satisfy the purposes of the experiments undertaken. For this purpose, Dr. Eric F. Wood, of Princeton University and Scientific Systems, Inc. of Boston, were engaged to develop a time series model that could be used for determining frequency of sampling and to develop a guideline for determining duration of experiments, including the number of samples to be taken to produce statistically acceptable results.

A comprehensive listing of the parameters to be analyzed for is included in Table 1. This listing includes parameters from the National Interim Primary Drinking Water Regulations, the EPA proposed Secondary Regulations, and parameters recommended by the National Academy of Science's "Committee to Review the Potomac Estuary Water Treatment Plant Project."

The ultimate objective under the pilot plant program is the evaluation of the quality of the water produced by the pilot plant. Establishing the basis for such an evaluation was hampered by a number of unknowns. These included:

- No evidence that a procedure exists for using a similar raw water source, tidal estuary influenced by wastewater discharges, as a source for domestic water supply.

- No information on published or generally accepted standards for evaluation of many of the parameters considered essential for monitoring the water quality in this study.

- No basis for assurance that the public will accept any quality of water produced from the estuary source.

- No real understanding of how many of the constituents that make up water quality affect public health.

In view of the foregoing obstacles it was decided to evaluate the quality of the treated water by: 1) comparison with nationally recognized standards which had been proposed or in effect, and, 2) comparison of all parameters with a locally treated water currently being supplied to the public.

Summary of Modeling Efforts

The variability and changes in the water quality of the estuary were analyzed using the EPA Dynamic Estuary model as calibrated and verified by the Annapolis Field Station. The model was used to generate three months of simulated hourly quality data. Two design simulations were conducted for subsequent statistical analysis: 1) Summer: average inflow: frequent local thunderstorms; 2) Winter: average inflow: average local thunderstorms. The following water quality parameters were simulated and analyzed for variability:

1) "Dissolved minerals" including TDS, Cl, specific conductance, SO_4, Hardness and Alkalinity, some of which were handled by cross-correlation and one or more, of which, were handled by simulation.
2) "Heavy metal", a representative heavy metal was simulated.
3) "Pesticide", (as assumed level).
4) Fecal Coliforms
5) DO
6) BOD
7) NH_3
8) NO_2
9) NO_3
10) PO_4

The variability time frame was one-hour for simulation. Variability in inputs were made with respect to tides, inflows, storm water overflow and wash-off, and sewage effluents for quantity and quality as appropriate. The following periodicities were captured by the simulation: 12-hour tides, 24-hour sewage, ±3-days rains, and 1-week sewage.

Some observations on variability as a result of the model simulation runs were:

- Summer simulation showed much greater changes in parameter concentrations within tidal cycles than did winter simulations.

- Both summer and winter plots showed sharp random increases throughout the 3-months of simulation, primarily due to rainfall runoff.

- Daily variations in constituent concentrations are caused by a combination of all types of discharges to the system (CSO, NPS loads, STP loads, upstream flow loadings), along with other impacts.

The simulation of salinity buildup and water quality at the anticipated intake of a future full scale water treatment plant was performed to aid in the development of the recommended blend of raw water for the pilot plant. The modeling effort simulated low flow conditions in the estuary for the year 2030 in the vicinity of Chain Bridge. The simulation suggests that extensive use (up to 3-months) of the estuary water, under conditions of the 1930 drought, is not likely to cause TDS to exceed 500 mg/l in the intake water for a future estuary water treatment plant, if the extraction rate is less than 200 mgd. Further, the extensive use of the estuary water under conditions of the 1930 drought and at extraction rates less than 200 mgd is not likely to cause health related parameters for heavy metals and organics, when related to the estuary water quality, to exceed the maximum contaminant levels for treated drinking water contained in the EPA Interim Primary Drinking Water Regulations.

Testing and Evaluation Program

The testing and evaluation program to determine the feasibility of producing potable water from the Potomac River addressed four issues. First the input waters to the pilot plant were selected to provide influent water quality equivalent to or worse than that which is expected to occur should a full scale treatment plant be built. Second, the treatment system and the individual processes that comprised it were selected so that, based on present knowledge and technology, a potable water could be produced. Third, the data to be obtained from the testing program was specified so that it satisfactorily described the quality of the water being treated, the performance of the individual treatment processes, and the potability of the finished water produced by the system. Finally, collection of data and information was recommended to permit an estimate of the operational costs of a full scale plant that could satisfactorily treat the estuary water.

The input water selected for testing should reflect pollutants that are present in the Blue Plains effluent, contaminants that can be introduced to the estuary from other point and nonpoint sources, and the variability in the composition of the estuary produced by tidal, seasonal, hydrologic and other factors. Blue Plains wastewater obtained before filtration and disinfection was selected as one constituent of the designed influent mixture. Potomac estuary water obtained near the site of the pilot plant was selected as the other component. A minimum flowby of 100 mgd was assumed at all times in the Potomac at Little Falls. A maximum withdrawal rate of about 200 mgd of estuary water was anticipated based on a statement in the summary report of the NEWS. This could result in a maximum transport of 100 mgd of Blue Plains effluent upstream to the intake site of a full scale plant. This simplified approach implies under worst conditions a minimum dilution of one part Blue Plains effluent and one part estuary water during periods of prolonged drought. This is not likely to be the case. The variability introduced by tides and seasonal factors, and the cycling of the treated water will interject a major influence over time in the quality of the mixture of the estuary water. Based on our analysis of these factors, a mixture of one part secondary wastewater effluent and two parts Potomac River estuary water was specified to represent the quality of input water to be used initially in the project.

It was decided that during the first year the treatment plant should be operated in a mode that represents the most widely accepted standard practice--coagulation, sedimentation, filtration, and disinfection. This treatment is to be augmented by unit processes recognized as being responsive to the concern for organics--i.e., granular activated carbon and aeration. During the first year the entire combined flow would then be split equally between the two carbon systems, one operated in the downflow mode and one as an upflow system. The two effluents are then combined and chlorinated for disinfection. Alum would be used as the coagulant since it is most widely used for treating surface waters. It is anticipated that chlorine would be added only for disinfection and only after carbon adsorption during the first year. Reverse osmosis would be evaluated on the side stream during this period. Figure 1 illustrates the process train specified for the first year of operation.

During the second year modifications could be made to the treatment process train to enable a number of other factors to be investigated. It is anticipated that they could include some of the following: 1) use of disinfected final Blue Plains wastewater effluent, 2) addition of dissolved salts and additional testing of demineralization systems, 3) use of lime and magnesium carbonate for coagulation and softening, 4) evaluation of biological activated carbon, 5) evaluation of different oxidants and disinfectants, and 6) other testing program considerations that arise as the project proceeds.

A rigorous sampling program was devised to provide the basis for evaluating the performance of the pilot plant. The sampling program also covered the need to obtain data for verification of the accuracy of the estuary water quality model and the time series model, both of which play a prominent role in the evaluation process. The sampling frequency for all parameters to be measured during the first year of the pilot plant's operation is presented in Table 2. Changes in this sampling frequency will probably be made during the program as knowledge is gained about the types, concentrations, and variabilities of the pollutants present, and based on future use of the time series model. At the outset some parameters will be measured on a continuous or semi-continuous basis. These include: turbidity, TOC, pH, temperature, and chlorine residual. A few parameters such as dissolved oxygen and coliforms are scheduled to be determined using daily grab samples. Most inorganic parameters, including trace metals are to be measured using daily composite samples. Most specific organic compounds are scheduled for weekly composite samples. Initially, efforts are to be made to detect all organic parameters listed in Table 1 for a period that includes summer and winter effects.

Nineteen sampling points throughout the system of the demonstration plant were considered critical to evaluation of the effectiveness of unit process operations and/or the quality of water produced by the pilot plant. Additional points would be located on one or more public water supply systems in the Washington, D. C. area. These latter points enable the collection of information on the quality of water produced by such systems to be compared against the same parameters used to evaluate the water produced by the pilot plant. The sampling station locations for the pilot plant are presented in Table 3.

A large portion of the laboratory analysis work relates to analyses that probably will be performed by specialized laboratories. These include: radiological, bacteriological (other than SPC and Coliform), and toxicological testing. The testing program calls for the remainder of the work to be conducted in three laboratories that could be established for the project. One laboratory would handle all organic and inorganic analysis. A second would handle the microbiological work. The third laboratory, located in the pilot plant facility, would conduct routine and process control analysis.

The project design calls for the plant to be operated continuously (24-hours per-day, 7-days per-week) for two years. This period is to be proceeded by a predemonstration phase of six-months to enable the project team to become thoroughly familiar with the pilot plant, the test protocols, and to conduct the predemonstration sampling that is required.

Final evaluation of the results of the T & E Program essentially involves three facets. These include: 1) quality of water produced by the pilot plant; 2) effectiveness of the unit processes that are tested; and, 3) projection of costs associated with staffing and operation of the pilot plant.

The quality of water produced by the pilot plant will be evaluated against existing, proposed, or revised primary and secondary drinking water standards promulgated by EPA prior to the date this demonstration project is completed. In the absence of EPA proposed or promulgated standards it was assumed that no generally recognized and nationally accepted or proposed standards or regulation existed against which to evaluate the remaining water quality parameters listed in Table 1. To provide a basis for comparing water quality produced by the pilot plant with a currently accepted drinking water supply, identical and simultaneous laboratory analysis of all parameters in Table 1 are to be made of the treated water from the pilot plant and the treated water from other water supply systems in the Washington, D.C. area. It is important to note that no attempt is intended to be made in this evaluation of water quality, using those parameters for which there are no existing or proposed standards, to determine if the water is or is not an acceptable water from a public health standpoint. The demonstration is intended to determine if, and under what conditions, the Potomac River estuary water can be treated to be at least as good in quality for the parameters measured as the water produced for human consumption by other water supply systems in the Washington metropolitan area.

The parameters used to provide the basis for discussing the relative efficiencies and effectiveness of unit processes would be those associated with recognized acceptable practices for water treatment methodology and reflective of the purpose for which the unit process is incorporated in the treatment train. In the case of granular activated carbon the evaluation would be based on parameters contained in the proposed or final regulations issued by EPA for the "control of organic contaminants in Drinking Water."

It is expected that careful records will be kept on the staffing and expenditures required to operate the pilot plant. On the basis of the information obtained, an estimate would be made of the staffing requirements and associated operating and maintenance costs for systems producing 100 mgd and 200 mgd of treated estuary water. It is recognized that scaling up costs from 1 mgd to 100 mgd or greater for some unknown time in the future is difficult. Under these circumstances a base year of 1981 has been suggested and the future plant costs would be projected for two successive 5-year periods using an 8% inflation factor. Cost estimates would be expressed in ranges that reflect a plus or minus 10-percent spread.

SUMMARY

A one-million gallon per day pilot treatment plant has been designed and is being constructed to evaluate the feasibility of treating the Potomac River estuary water for domestic use. The source has an abundance of fresh water during periods of normal flow in the river. During periods of low flow the quality of the estuary water deteriorates significantly as it is impacted by tidal action and discharges from the Blue Plains Regional Sewage Treatment Plant.

The 1 mgd pilot plant incorporates the normal process train to treat a surface supply to meet current drinking water standards. It also incorporates additional unit processes for treating anticipated raw water quality problems associated with high total dissolved solids, organics, heavy metals, viruses and toxic substances. It will be possible to operate many of these unit processes in parallel, in series, and as side streams, giving considerable flexibility for making comparative evaluations.

The primary purpose of this demonstration project is to determine if a water quality acceptable for drinking can be produced under the worst conditions that might prevail in the estuary. The conditions likely to prevail were established by a water quality modeling program patterned after the EPA Dynamic Estuary Model. The statistical validity of the sampling process and analytical precision will be guided by a "time series model" expressly developed for this project. Existing and proposed drinking water standards will be used when applicable for evaluation of treated water quality. Since there are no specific standards for many of the parameters used in the evaluation, the treated water will be compared with treated water from an accepted source.

Finally, the demonstration will provide information on the staffing, operating, and maintaining a plant for this purpose. This information will be useful in developing estimates on the design and operation of a full scale plant that might be constructed under the same or similar conditions.

Specific and more detailed information on the testing and evaluation program is contained in the Report recently submitted to the Corps of Engineers on this subject.[4]

REFERENCES:

1. North Atlantic Division, U.S. Army Corps of Engineers, Northeastern United States Water Supply Study, Interim Report, Critical Choices for Critical Years. (Nov. 1975).

2. Malcolm Pirnie, Inc., Design for the Experimental Estuary Water Treatment Plant. (1977).

3. Malcolm Pirnie, Inc., Design Memorandum for the Experimental Estuary Water Treatment Plant. (March 1976).

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TABLE 1

EXPERIMENTAL ESTUARY WATER TREATMENT PLANT

LIST OF PARAMETERS TO BE ANALYZED

I. PHYSICAL

- **Color
- **Corrosivity
- **Odor
- Residue
  - Total
  - Filtrable
  - Nonfiltrable
- Specific Conductance
- Taste
- Temperature
- *Turbidity

II. INORGANIC

- Alkalinity
- Aluminum
- Antimony
- *Arsenic
- Asbestos
- *Barium
- Beryllium
- Boron
- Bromide
- *Cadium
- Calcium
- **Chloride
- Chlorine Demand
- Chlorine Residual
  - Free
  - Combined
- *Chromium
- Cobalt
- **Copper
- Dissolved Oxygen
- *Fluoride
- Hardness
- Iodine
- **Iron
- *Lead
- Lithium
- Magnesium
- **Manganese
- *Mercury
- Molybdenum
- Nickel
- Nitrogen
  - Ammonia
  - *Nitrate
  - Nitrite
- Orthophosphate
- Ozone
- pH
- Potassium
- *Selenium
- Silica
- *Silver
- Sodium
- **Sulfate
- Thallium
- Tin
- Titanium
- Vanadium
- **Zinc

TABLE 1 (continued)

III. ORGANICS

- A. Aliphatic Halogenated Hydrocarbons
  - Methane Derivatives
    - dichloromethane
    - trichlorofluormethane
    - dichlorodifluormethane
    - carbon tetrachloride
    - trihalomethanes
  - Ethane Derivatives
    - 1,1 dichloroethane
    - 1,2 dichloroethane
    - hexachloroethane
    - 1,1,1 trichloroethane
    - 1,1,2 trichloroethane
    - 1,1,2,2 tetrachloroethane
    - ethylene dibromide
  - Unsaturated Hydrocarbons
    - trichloroethylene
    - tetrachloroethylene
    - vinyl chloride
    - 1,1 dichloroethene
    - 1,2 dichloroethene
    - 1,3 dichloropropene
    - hexachlorobutadiene
    - 2 chlorovinyl ether
    - 1,1 dichloroethylene
  - Other Halogenated Compounds
    - 1,2 dichloropropane
    - bis (2-chloroethyl) ether
    - bis (2-chloroisopropyl) ether
- B. Cyclic Aliphatic Compounds
  - Chlorinated Hydrocarbons
    - *lindane and BHC
    - kepone
    - toxaphene
  - Cyclodienes
    - hexachlorocyclopentadiene
    - aldrin
    - dieldrin
    - chlordane
    - heptachlor
    - heptechlor epoxide
    - *endrin
    - *methoxychlor

TABLE 1 (continued)

III. ORGANICS (continued)

C. Aromatic Hydrocarbons

- 3,4 benzofluoranthene
- benzo (k) fluoranthene
- 1,12 benzoperylene
- fluoranthene
- indeno (1,2,3-cd) pyrene
- benzo (a) pyrene
- 11,12 benzofluoranthene
- 3,4 benzopyrene

Benzenes

- benzene
- toluene
- xylenes
- ethylbenzene
- propylbenzene
- styrene

Halogenated Aromatics

- chlorinated naphthalenes
- chlorobenzene
- dichlorobenzenes
- trichlorobenzenes
- polychlorinated biphenyls
- bromobenzene
- DDT
- DDE
- DDD
- chlorophenols
- pentachlorophenol
- 4-bromophenylphenyl ether
- 4-chlorophenylphenyl ether
- hexachlorobenzene
- chlorophenoxys
- 2,4 dichlorophenol

Other Aromatic Hydrocarbons

- nitrobenzene
- phthalate esters
- atrazine
- benzidine
- 1,2 diphenylhydrazine
- nitrochlorobenzene
- phenol
- dinitrotoluene

TABLE 1 (continued)

III. ORGANICS (continued)

D. Other Organics

- 2,3,7,8 tetrachlorodibenzo-p-dioxin
- tricresylophosphate
- *2,4,D
- *2,4,5-TP Silvex
- Cyanide
- MBAS
- Total Organic Carbon
- Total Organic Chlorine
- Total Organic Nitrogen

IV. RADIOLOGICAL

- *gross alpha
- *gross beta
- *radium
- *strontium
- *tritium

V. BIOLOGICAL

- adeno viruses
- enteric viruses
- polio viruses
- *coliform
  - *total
  - fecal
- standard plate count
- salmonella
- protozoa
- helmintus
- nematodes
- bacterial endotoxins

VI. TOXICOLOGICAL

- ames bacterial systems
- mammalian cell cultures

*Included in the National Interim Primary Drinking Water Regulations.

**Included in the EPA Proposed Secondary Regulations.

TABLE 2

SAMPLING AND ANALYTICAL REQUIREMENTS

EXPERIMENTAL ESTUARY WATER TREATMENT PLANT

ANALYSIS	SAMPLING FREQUENCY AT SAMPLING LOCATION																			
	1	2	3	4	5	6	7	3	9	10	11	12	13	14	15	16	17	18	19	20
PHYSICAL (1)																				
Color			D			D										D		D		D
Odor																D				D
Residue																				
Filtrable	D	D		D									D				D·			D
Nonfiltrable	D	D	D						D											
Sp. Conductance		C		C																
Taste (2)																D		D		D
Temperature	C	C	C										C			C				C
Turbidity	D	C	D	C	D				D			D				C		D		C
INORGANIC																				
Alkalinity	D	D	D													D				D
Arsenic	W	W	W													W	W		W	W
Asbestos	W	W	W													W	W		W	W
Calcium	D	D														D	D			D
Chloride	D	D											D			D	D			D
Chlorine Demand													G							
Chlorine Residual																				
Combined																G				G
Free																G				G
Dissolved Oxygen	G	C				G							G			G				G
Fluoride	D	D														D				D
Hardness	D	D											D			D	D			D
Iodide	D	D	D													D	D		D	D
Metals (3)	D	D	D													D	D		D	D
Nitrogen																				
Ammonia	D	D	D			D										D				D
Nitrate	D	D	D													D				D
Nitrite	D	D	D													D				D
Orthophosphate	D	D	D													D				D
Ozone (4)						G								G				G		
pH	C	C	C		C								C			C		C	C	C
Silica	D	D	D													D	D		D	D
Sulfate	D	D	D													D	D		D	D
ORGANICS																				
Cyanide	D	D	D													D	D		D	D
MBAS	D	D	D													D	D		D	D
Synthetic (5)			B													B		B		B
THM's (6)			T										T			T		T		T
T O Carbon (7)	D	D	D	C		C	C	C	C	C	C	C	D			D		D		D
T O Chlorine (7)			G										G			G		G		G
T O Nitrogen (7)	D																			

TABLE 2 (continued)

SAMPLING AND ANALYTICAL REQUIREMENTS

EXPERIMENTAL ESTUARY WATER TREATMENT PLANT

ANALYSIS	SAMPLING FREQUENCY AT SAMPLING LOCATION																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
RADIOLOGICAL																				
All Parameters (8)	W	W														W		W		W
BIOLOGICAL																				
Bacterial Endotoxin	M	M											M			M		M		M
Coliform																				
Fecal	G	G											G			G		G		G
Total	G	G											G			G		G		G
Parasites	M	M											M			M		M		M
Salmonella	M	M											M			M		M		M
Standard Plate Count	G	G											G			G		G		G
Viruses (9)	M	M											M			M		M		M
TOXICOLOGICAL																				
Ames Bacterial Systems																W				W
Mammalian Cell Cultures																M				M

B-bi-monthly composite; C-continuous; D-daily composite; G-daily grab; M-monthly; T-daily grab (see note 6); and, W-weekly composite.

(1) Corrosivity and total residue to be calculated based on other analyses.

(2) To be sampled at end of first year.

(3) Includes all metals in Table 1.1.

(4) Analyzed during ozone disinfection.

(5) Includes all organics in Table 1.1

(6) Locations vary depending on chlorine application points.

Daily composite consisting of two grab samples will be combined into one three day and one four day composite resulting in two THM analyses per week per sample location.

Finished water samples from other water systems and the EEWTP will be analyzed for seven day THM formation potential once per week.

(7) T O - Total Organic

(8) Includes all parameters in Table 1.1.

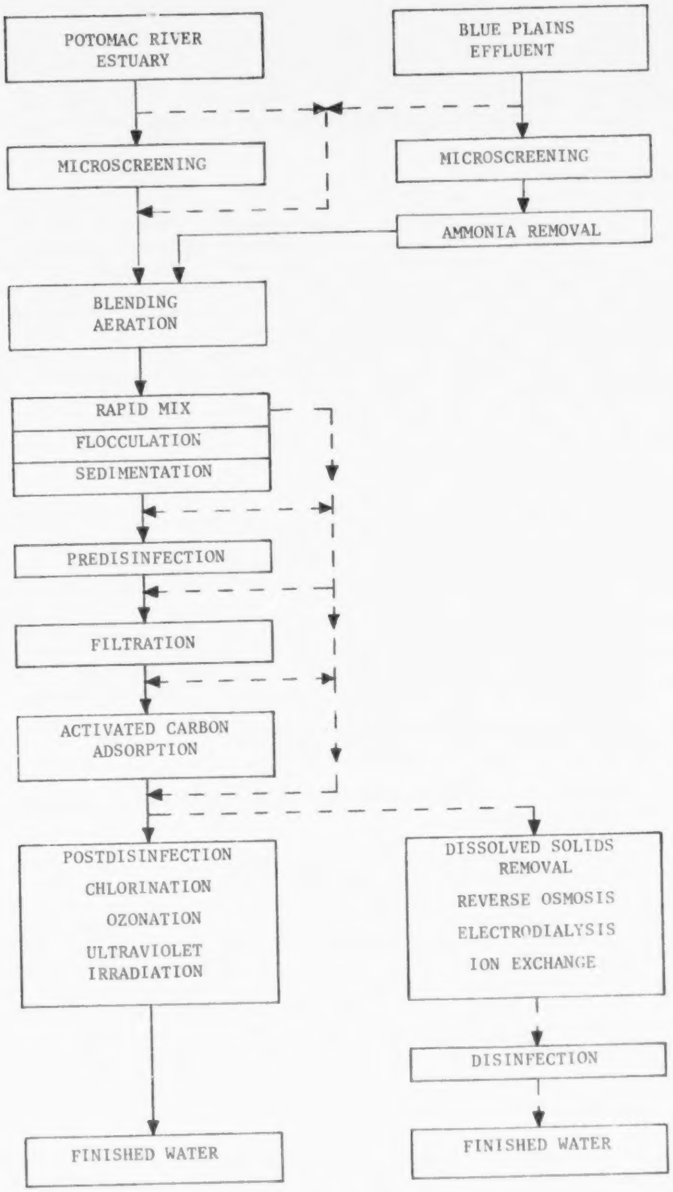
(9) Includes adeno, enteric and polio.

TABLE 3

SAMPLING LOCATIONS

EXPERIMENTAL ESTUARY WATER TREATMENT PLANT

Location Number	Description
1	Blue Plains Effluent
2	Estuary Water
3	Blended Water Prior to Microscreens
4	Aeration Tank Effluent
5	Recarbonation Tank Effluent
6	Filtered Water Clear Well Effluent
7	Carbon Column Effluent
8	Carbon Column Effluent
9	Carbon Column Effluent
10	Carbon Column Effluent
11	Carbon Column Effluent
12	Carbon Column Effluent
13	Carbon Column Clear Well Effluent
14	Ozonation Tank Effluent
15	Ultraviolet Irradiation Effluent
16	Chlorine Contact Tank Effluent (Finished Water)
17	TDS Removal Effluent
18	TDS Disinfection Effluent
19	Recovered Alum/Lime
20	Public Water Supply System(s) Effluent



FLOW SCHEMATIC
FIGURE 1

ADMINISTRATIVE STEPS TO A REGIONAL WATER REUSE STUDY: THE ORANGE AND LOS ANGELES COUNTIES WATER REUSE STUDY

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INTRODUCTION

The Orange and Los Angeles Counties Water Reuse Study is a regional study of the major issues confronting water reuse in Southern California. The study was organized by six local agencies involved in water supply and wastewater management and six regional, state and federal agencies concerned with water quality management and planning. The study was implemented on June 27, 1978, and is now in progress. More than one year was required by the participating agencies to plan and organize the study and to obtain the necessary approvals and funds. The following is a brief summary of the administrative steps taken by the participants in this study during the study's formation.

BACKGROUND

Southern California is a water-deficient area which is in need of additional water supplies to forestall shortages in the future. Of the alternatives available for consideration, water reuse appears to be one of the most attractive for the following reasons:

1. The Federal Water Pollution Control Act of 1972 and its 1977 amendments mandate a high level of treatment for municipal wastewaters. Up to 500 mgd of high-quality wastewater will be available in the study area in the near future for reuse.

2. Water reuse technology has been proven by a number of successful projects; and

3. A potential reuse market of 400 mgd is estimated to exist in the study area.

Several agencies in the study area have conducted research in water reuse but have not been able to implement projects. The high cost of reclaimed water relative to fresh water (mostly due to treatment and a separate distribution system), and the unknown health effects of water reuse by groundwater replenishment have been compounded by institutional complexities which hinder reuse development. More than 100 water supply agencies who would have jurisdiction over the sale of reclaimed water exist in Southern California and create a complex marketing and financing structure. A regional study was an obvious means of attacking the problems and gaining interagency cooperation in an efficient manner.

BASIS FOR THE STUDY

Statewide and regional water shortages and the need for water reuse were documented in a report titled "Policy and Action Plan for Water Reuse in California". This report, adopted by the State government in January 1977, directed State regulatory agencies to assist research and demonstration projects related to water reuse. Additionally, the report recommended the development of regional plans for water reuse. On this basis, six local agencies in Southern California interested in water reuse joined with six regional, state and federal regulatory and planning agencies and developed a proposal for a regional water reuse study.

AGENCIES INVOLVED IN THE STUDY

The six local agencies which comprise the principal participants of the study are as follows:

1. City of Los Angeles, Bureau of Engineering (City)
2. City of Los Angeles, Department of Water and Power (DWP)
3. The County Sanitation Districts of Los Angeles County (LACSD)
4. The Metropolitan Water District of Southern California (MWD)
5. Orange County Water District (OCWD), and
6. Orange County Sanitation Districts (OCSD)

The following six regional, State, and Federal agencies involved in the study as overseers, are:

1. U.S. Environmental Protection Agency (EPA)
2. California State Water Resources Control Board (SWRCB)
3. California Department of Water Resources (DWR)
4. Southern California Association of Governments (SCAG)
5. California Regional Water Quality Control Board, Los Angeles Region (LAWQCB), and
6. California Regional Water Quality Control Board, Santa Ana Region (SARWQCB)

FORMATION OF THE STUDY

In May 1977, the SWRCB (which is the agency that oversees water resources development in California) placed the proposed water reuse study on the 1977-78 Project Priority List in a fundable category. This action made the proposed reuse study eligible for Clean Water Grant Funds from the EPA. The six local agencies were expected to conduct the study and to provide the local share of funds to pay for the study.

The six local agencies formed a Joint Powers Group which conducted a series of organizational meetings and accomplished the following:

1. A formal commitment to participate in the study was elicited from each of the six local agencies.

2. An administering agency was designated to apply for and accept the grant award on behalf of the study.

3. Local costs of the study were allocated equally among the six participants.

4. A revolving fund was created by a $200,000 contribution from each agency.

5. Office space was provided by one of the six agencies.

6. A joint powers agreement was developed and executed.

A Management Board, consisting of one representative from each of the six Joint Powers agencies and the six overseeing agencies was formed to provide direction and management of the study. The Management Board hired a project manager and staff, approved the work plan, and approved a $4 million budget.

The 12 agencies involved in the study prepared a Plan of Study and applied to the SWRCB for a funding commitment under the Clean Water Act. A Step 1 Clean Water Grant for planning was awarded in July 1978. The grant was to provide 75 percent of the study costs. SWRCB agreed to provide for half of the unfunded cost and required the six Joint Powers agencies to provide the remainder.

ORGANIZATION AND TASK SUMMARY

The organizational structure of the Orange and Los Angeles Counties Water Reuse Study is shown on Figure 1. The eight tasks depicted on the figure are summarized below:

Task 1: Health Effects

The Health Effects Task is a comprehensive study of the health effects of using reclaimed water to recharge a groundwater basin which is a source of potable water supply. Specific subtasks include: the evaluation of soil filtering effects, the characterization of reclaimed water quality, the analysis of toxicity of reclaimed water, and an epidemiologic survey of reclaimed water users. The goal of this task is to develop criteria for recharge.

Task 2: Preliminary Engineering

Potential reuse applications and reclaimed water sources are to be identified and described in this task. Such information will be used in Marketing and Feasibility studies in Task 3.

Task 3: Market and Project Feasibility

A detailed analysis of potential reclaimed water users and purveyors will be conducted in this task to determine the feasibility of reuse. Feasible reuse projects will be identified.

Task 4: Economic and Financial Basis for Reuse

The benefits and costs of large-scale reuse will be evaluated on a regional and statewide basis. Problems of financing reuse projects will be evaluated and resolved. Alternative means of financing will be developed.

Task 5: Pilot and Demonstration Projects

This task is included for the purpose of evaluating new treatment technology or new reuse applications if the Engineering, Market and Economic Tasks identify such a need.

Task 6: Public Participation

Two-way communication between the study participants and the community will be developed to ensure implementability of the reuse plan. This task includes formal public hearings on all proposed plans and on the environmental documents to be prepared as a part of the study.

Task 7: Facilities Plan

A regional engineering and financial plan will be prepared for the staged construction of new reuse facilities. Procedures for implementation and institutional arrangements will be developed as a part of the plan

Task 8: Areawide EIS/EIR

The regional environmental impacts of implementing the Facilities Plan will be evaluated and disclosed in a format meeting the requirements of both the California Environmental Quality Act and the National Environmental Policy Act.

PROGRESS TO DATE

The Orange and Los Angeles Counties Water Reuse Study is now underway. The study began in June 1978 and is expected to be completed in 1981. Early task work has focused on economic studies and on the identification of reuse applications. Tasks are being conducted by the participating agencies, the study staff, and a consultant hired by the study for market evaluation. The existence of a large potential market for reclaimed water has been confirmed and steps are now being taken to determine the feasibility of supplying that market with reclaimed water.

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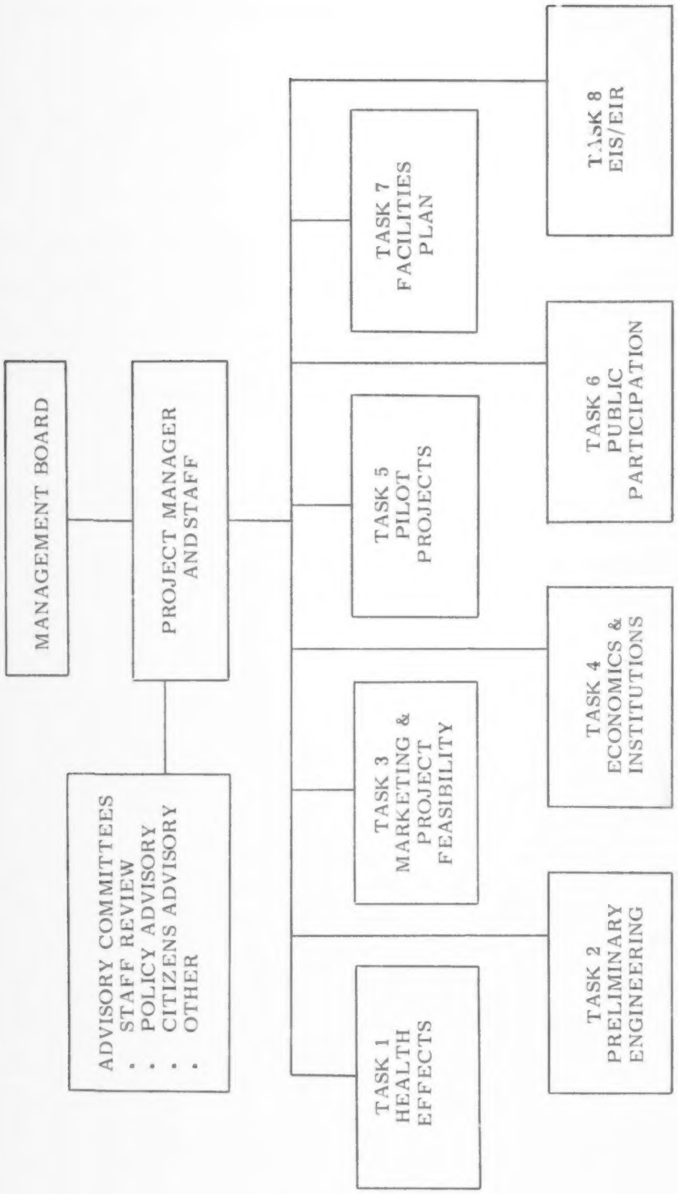

FIGURE 1 - GENERAL ORGANIZATION OF STUDY

USE OF RECLAIMED WASTEWATER
TO OPERATE A SEAWATER INTRUSION CONTROL BARRIER

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The Oxnard Plain is a prime agricultural area in Southern California. The Oxnard aquifer is a major source of water for farming operations on the plain and this aquifer is being overdrafted at an average rate of 8,700 acre-feet per year. This overdraft situation has effected the hydraulic characteristics of the aquifer, such that seawater is intruding into the freshwater zones of the groundwater basin.

Contamination of fresh water aquifers has reduced the water quality in an agricultural intensive area, which in turn has increased demand for better quality imported water. Several local wells have been placed out of service with adverse effects on farming operations in the area. The future impacts of this situation include adjudication by the State of the groundwater basin, increasing numbers of contaminated wells and insufficient water supplies to meet future demands. Results of extensive studies show that seawater intrusion in the Oxnard aquifer will become increasingly serious under any land use alternative unless a control plan is implemented.

The Ventura Regional County Sanitation District (VRCSD), which was formed to direct county-wide sanitation efforts, developed recommendations in Areawide Waste Treatment Management Planning (208) to halt seawater intrusion. As a result of the 208 Plan, the district has retained PRC Toups Corporation, Consulting Engineers, to assist in conducting a 201 Facilities Plan for Wastewater Reclamation and Reuse in the coastal plain. The purpose of this plan is to further analyze seawater intrusion into coastal aquifers and to recommend the best project for reclaiming treated wastewaters presently discharged to the Pacific Ocean.

An injection/extraction well system is a direct solution to the seawater intrusion problem in the Oxnard aquifer. Injection of reclaimed water to form a hydraulic barrier controls the landward movement of the saline water, and extraction wells inland of the injection wells create a hydraulic separation by removing the reclaimed water prior to its interaction with the fresh water zone of the confined Oxnard aquifer.

Reclamation of wastewater from the Oxnard Wastewater Treatment Plant to create a seawater intrusion control barrier and to irrigate agricultural sites has been evaluated as a viable reuse alternative. A process train which includes multi-media filtration, reverse osmosis (or reverse osmosis in conjunction with a mineral source control program) and chlorination will be utilized to produce reclaimed water of suitable quality. Agricultural irrigation with reclaimed water provides for a reliable and abundant alternate water supply for the Oxnard Plain. This alternative is technically feasible and would have the beneficial effect of reducing the overdraft situation.

SEAWATER INTRUSION

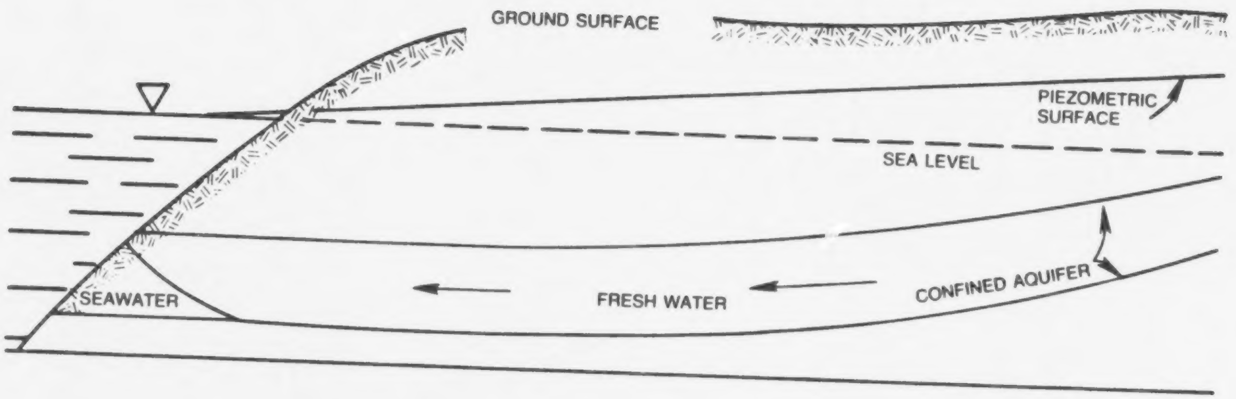
Seawater intrusion into fresh groundwater aquifers has been a documented problem in various coastal regions of the United States. In hydraulically connected fresh and salt water zones, as fresh water levels decrease the salt water intrudes thereby deteriorating the water quality of the aquifer. The effects of such contamination can be extensive, in that it may effect not only a community's water supply but the economic and social structure as well. There are alternative measures which may be implemented once this phenomena has occurred. A seawater intrusion control barrier utilizing reclaimed water is one possible solution.

There are various factors which lead to the seawater intrusion phenomena. To get a better understanding of this type of situation, general background information, hydrologic conditions and project area characteristics will be described.

Background

Under natural conditions fresh water is discharged into the ocean where coastal aquifers come in contact with the sea. Demand on groundwater can alter this situation causing salt water to penetrate inland in aquifers. This action may directly affect natural underground flows, permeability and other physical parameters in addition to causing indirect environmental, economical and sociological concerns.

An aquifer is like a large underground storage reservoir. Water enters the aquifer by means of natural or artificial recharge and leaves by natural flows or is extracted by wells. There are two basic classifications for aquifers: unconfined and confined. An unconfined aquifer can be described as one which has a water table as its upper surface; whereas, a confined aquifer is under pressure beneath relatively impermeable strata. The unconfined aquifer is the type which will be discussed in the following sections. A diagrammatic sketch of a coastal groundwater basin not subject to seawater intrusion is shown in the following figure. The piezometric surface on the diagram indicates the level at which



CONFINED GROUNDWATER BASIN NOT SUBJECT TO SEAWATER INTRUSION water stands in wells. Under equilibrium conditions there is no energy gradient within the saline wedge to provide movement. The seawater front assumes the shape of an inclined wedge which slopes landward, advancing or receding in response to changes in the hydraulic gradient. (1) Few incidences of salt water intrusion can be attributed to natural phenomena. Salt water and fresh water often share the same formation, however, man's activities, primarily pumping more water from an aquifer than can be naturally replenished, are responsible for destroying the hydraulic continuity between fresh and saline waters. (2)

Seawater will continue to move inland as long as the water table remains below sea level and slopes toward land. This situation can be reversed only by returning groundwater levels to near natural conditions. Once saline water has entered a basin, the fresh water in the degraded portion is no longer available as a source of potable water. Restoration of the water to acceptable levels of quality may require many years. (3)

Hydrological Conditions

Permeable geologic formations which allow water to move under ordinary field conditions are defined as aquifers. Aquitards are confining layers of relatively low permeability such as clays and silts. An aquifer may be bounded by impermeable or permeable formations.

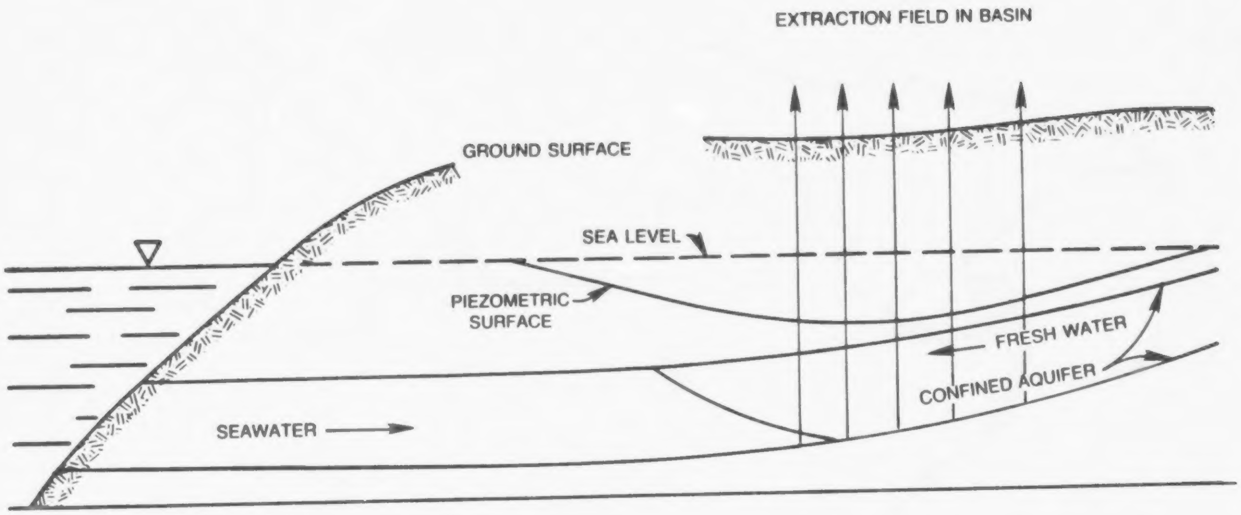
In coastal areas where extraction from the underground aquifers exceed inflow rates, seawater intrusion may occur. To maintain equilibrium between fresh water and seawater (due to differences in density), 1.025 feet of freshwater is required for every foot of seawater. Variations in the protective elevations are determined by the varying depth of the aquifer bottom. The maintenance of a protective elevation can be computed from an equilibrium equation, assuming that the pressure of the barrier must equal that exerted by seawater to halt its progression inland. The overdraft of an aquifer by extraction wells can effect the equilibrium as is indicated by the following figure of a groundwater basin subject to seawater intrusion.

OXNARD PLAIN SITUATION

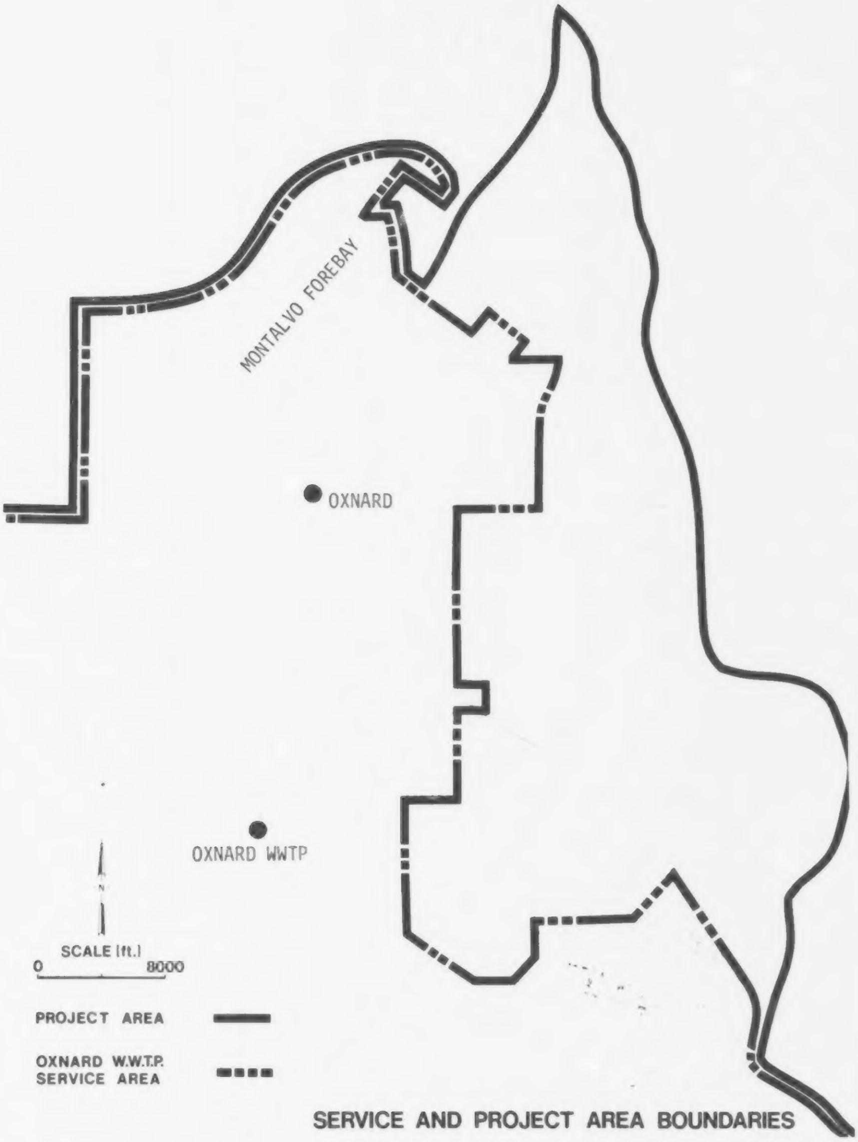
The specific area of concern in this paper relates to seawater intrusion factors which impact the Oxnard Plain. Present impacts include hydraulic alterations and reduced water quality in the groundwater basin, increased demand for imported water and local wells being put out of service. Governmental concerns and economic impact to the agricultural community are other significant factors. The seawater intrusion phenomena will have future ramifications if the present situation is not altered. The following sections will describe seawater intrusion in Oxnard, the impacts and concerns.

Description

The project area encompasses approximately 43,000 acres and is shown in the second figure following. It consists of all lands overlying



CONFINED GROUNDWATER BASIN SUBJECT TO SEAWATER INTRUSION



SERVICE AND PROJECT AREA BOUNDARIES

the Oxnard Plain Groundwater Basin, including the Montalvo Forebay and El Rio spreading grounds. The service area is defined as that area where generated wastewater is tributary to the Oxnard Wastewater Treatment Plant within the 20 year planning period.

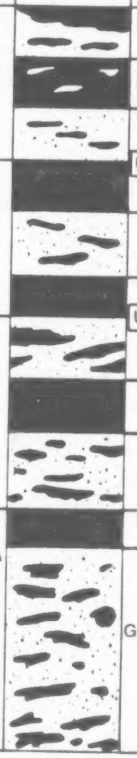
The Oxnard Plain is a broad alluvial plain composed of a number of smaller alluvial fans. The Plain was formed by deposition of clay, sand, and gravel from the Santa Clara River and Calleguas Creek drainage areas under conditions of moderate earth movement followed by erosion and deposition. Smaller alluvial fans, forming a piedmont in the north, represent deposits from smaller creeks draining that area. Windblown sands, back-bay deposits, and other shallow marine sediments also occur along the oceanfront.

Recent deposits in the coastal plain, consisting of alluvial sands and gravels, lagoonal silts and clays, and dune sands, were laid down during the post-glacial period. These deposits lie unconformably on the upper Pleistocene deposits and make up the Oxnard aquifer, the confining cap and the semi-perched zone.

The upper Pleistocene deposits consist of interbedded sands, gravels, silts and clays. These deposits form the upper aquitard that separates the Oxnard aquifer, the Mugu aquifer, the Mugu aquifer itself, and a lower aquitard that separates the Mugu aquifer from the water bearing deposits of lower Pleistocene Age. In the forebay area, near the community of Saticoy, the Oxnard and Mugu aquifers merge and both are in hydraulic continuity with the ground surface. This area is known as the Montalvo Forebay.

A schematic of the generalized geologic column is shown on the following page. This depicts the relative location of the various aquifers and associated aquitards.

The Oxnard aquifer, the most important water producer in the Oxnard basin, is composed of fine to coarse-grained sand and gravel. Within the project area the aquifer is a single unit of high permeability with no prominent silt or clay lens interruptions and has an average and maximum thickness of about 90 to 100 feet, respectively. Immediately below the Oxnard aquifer and separating it from the Mugu aquifer is an aquitard that is composed of silty clay with some interbedded sandy clay lenses. The average thickness of this aquitard in the project area is approximately 30 feet although the maximum thickness has been reported to be 150 feet. The material that forms the Mugu aquifer is fine to coarse-grained sand and gravel with some interbedded silty clay. Within the project area, this aquifer attains a maximum thickness of 250 feet, although the average thickness of this water-bearing zone is approximately 110 feet. Permeability at the Mugu aquifer ranges between 1,900 and 2,200 gallons per day per square foot (gpd/ft^2). In the forebay area, where the Santa Clara River enters the Oxnard Plain and near Mugu Lagoon, the Mugu aquifer merges with the Oxnard aquifer. It is reported to be in hydraulic continuity with the ocean, although there is no evidence of seawater moving laterally within the zone. (5)

AGE	GEOLOGIC UNIT	GRAPHIC LITHOLOGY	AQUIFER UNITS	MAXIMUM THICKNESS	GENERAL LITHOLOGY AND WATER - BEARING CHARACTER OF SEDIMENTS
RECENT	(RECENT DEPOSITS)		SEMIPERCHED ZONE	80	FINE-TO-MEDIUM-GRAINED SAND WITH SOME GRAVEL. INTERBEDDED SILT AND CLAY LENSES. UNDEVELOPED BY WELLS. LOCALLY DEGRADED BY RETURN IRRIGATION WATER.
			CONFINING CAP	150	SILT AND CLAY WITH FINE-TO-MEDIUM-GRAINED SAND LENSES. CONFINING MEMBER ABOVE OXNARD AQUIFER.
			OXNARD	160	FINE-TO-COARSE-GRAINED SAND WITH GRAVEL VARYING FROM GRANULE TO COBBLE IN SIZE. INTERBEDDED SILT AND CLAY LENSES. HIGH PERMEABILITY PRINCIPAL PRODUCING AQUIFER IN OXNARD BASIN. SUBJECT TO SEA-WATER INTRUSION.
			UNCONFORMITY		
LATE PLEISTOCENE	(UPPER PLEISTOCENE DEPOSITS)			150	SILT AND CLAY.
			MUGU	250	FINE-TO-COARSE-GRAINED SAND WITH GRANULES INTERBEDDED SILT AND CLAY LENSES. HIGH PERMEABILITY. LOCALLY DEVELOPED BY WELLS IN OXNARD BASIN. SUBJECT TO SEA-WATER INTRUSION.
				80	SILT AND CLAY.
			UNCONFORMITY		
EARLY PLEISTOCENE	SAN PEDRO FORMATION (LOWER PLEISTOCENE DEPOSITS)		HUENEME	300	FINE-TO-COARSE-GRAINED SAND WITH SILT AND CLAY LENSES. MODERATE TO HIGH PERMEABILITY. DEVELOPED BY FEW WELLS IN OXNARD BASIN. MAY BE SUBJECT TO SEA-WATER INTRUSION.
				170	SILT AND CLAY.
			FOX CANYON	550	FINE-TO-COARSE-GRAINED SAND WITH GRAVEL STRINGERS INTERBEDDED SILT AND CLAY. MODERATE PERMEABILITY DEVELOPED BY FEW WELLS IN OXNARD BASIN. MAY BE SUBJECT TO SEA-WATER INTRUSION
	SANTA BARBARA FORMATION (LOWER PLEISTOCENE DEPOSITS)			40	SILT AND CLAY.
			GRIMES CANYON	1500+	FINE-TO-COARSE SAND WITH GRAVEL. INTERBEDDED SILT AND CLAY. PROBABLE MODERATE PERMEABILITY. DEVELOPED BY FEW WELLS IN OXNARD BASIN MAY BE SUBJECT TO SEA-WATER INTRUSTION

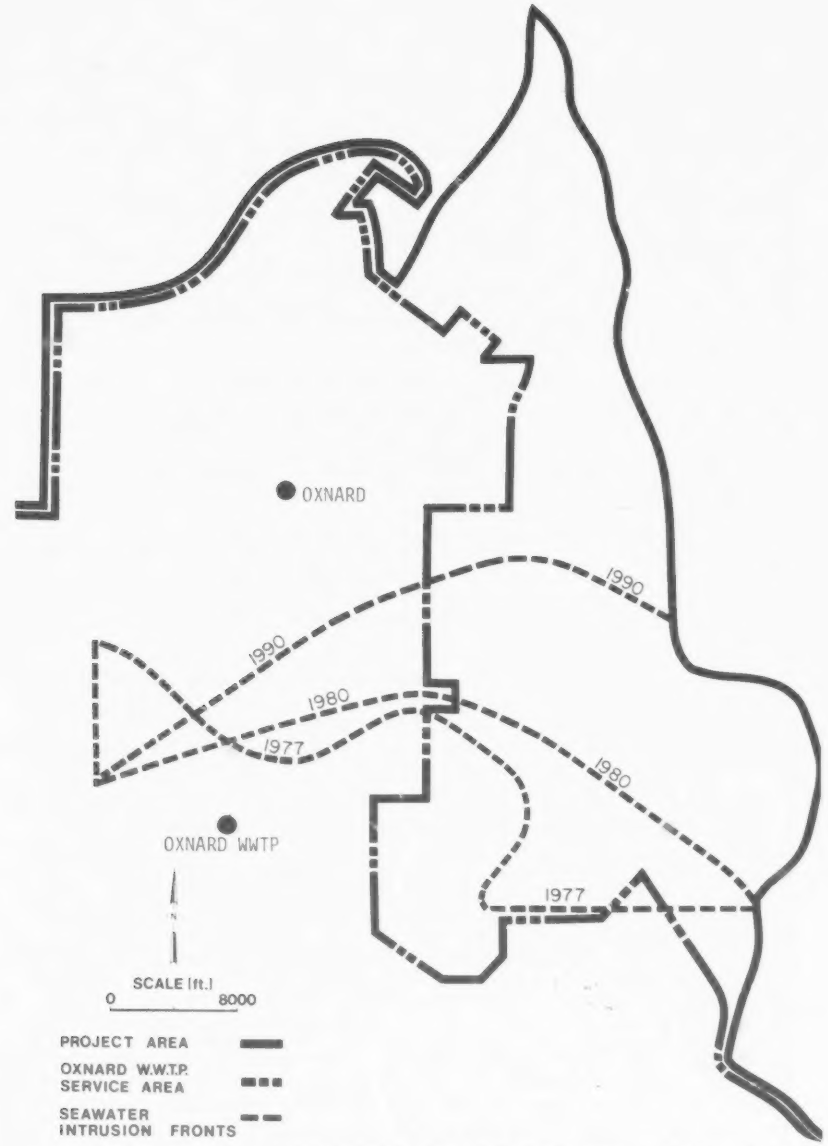
GENERALIZED GEOLOGIC COLUMN

Underlying the Mugu aquifer is an aquitard composed of silty clay which reaches a maximum thickness of 80 feet within the Oxnard basin. This aquitard is continuous except in the forebay area, where the Hueneme aquifer merges with the other water-bearing zones. The Hueneme aquifer is composed of irregularly interbedded sand, silt and clay, with some gravel, ranging in thickness from 100 feet within the City of Port Hueneme to about 300 feet north of the City of Oxnard. Permeability for this water-bearing zone is estimated to be 400 to 600 gpd/ft^2. This Hueneme aquifer is separated from the underlying Fox Canyon aquifer by an aquitard that is composed of silt and clay and which is absent only where the Fox Canyon aquifer merges with the Hueneme aquifer in the northern portion of the forebay area. Although the thickness of the aquitard in the project area is not known, the maximum thickness in the basin is approximately 170 feet.

Composed of the fine to coarse-grained sand with gravel stingers and interbedded silt and clay, the Fox Canyon aquifer is the second most important water producer in the project area. With a maximum thickness of approximately 550 feet in the Oxnard basin, permeability of this water bearing zone range from 200 to 400 gpd/ft^2. Besides merging with the Hueneme zone, the Fox Canyon is also in hydraulic continuity with both the overlying Mugu and Oxnard aquifers. The aquitard that separates the Fox Canyon and the underlying Grimes Canyon aquifer is composed of silt and clay, attaining a maximum thickness of about 40 feet in the Oxnard basin. The Grimes Canyon aquifer is composed of fine to coarse-grained materials, with a maximum thickness of more than 1,500 feet and has an areal extent corresponding to the Fox Canyon aquifer.

Groundwater supplies in coastal Ventura County, California are rapidly being intruded by seawater due to overdraft of existing groundwater supplies by agricultural operations. Overdraft of the Oxnard aquifer began prior to 1932, creating conditions which were conducive to seawater intrusion. By 1955, seawater was intruding at an increased rate contaminating the groundwater.

In 1974 a seawater-intrusion monitoring program was initiated on the Oxnard Plain. By the June-September 1974 sampling period, the seawater intrusion front had moved inland to a point where the intruded area covered approximately 17.9 square miles. Based on water resources studies, well logs and other survey data, the onshore portions of the Oxnard aquifer contained 833,900 acre-feet of water in the fall of 1975. During the 1977 seawater-intrusion sampling program, 75 well-water samples were collected in June and July. Results of the survey indicate that the total onshore intruded area in the Oxnard aquifer zone covered 20.6 square miles, an increase of 2.9 square miles over the intruded area of the previous year. (3) During the 27-year period, since seawater intrusion in the Oxnard aquifer zone was first detected, the intrusion front has moved inland during every monitoring period except 1976 when a small reversal was noted in the vicinity of Port Hueneme. Existing and projected seawater intrusion fronts in the project area are illustrated in the following figure.



EXISTING AND PROJECTED SEAWATER INTRUSION FRONTS

The annual overdraft of the Oxnard aquifer is found by adding the long-term decrease in storage to the landward underflow of groundwater at the coastline. The annual overdraft is approximately 8,700 AF/yr for the Oxnard aquifer.

The growing demand for water in the Oxnard Plain has led to overdrafting of the groundwater basin. The overdrafting of the Oxnard aquifer has resulted in the intrusion of that unit by seawater. The history of this situation and the probable legal and administrative requirements of this alternative have necessitated the combining of Ventura Regional County Sanitation District, United Water Conservation District, and Ventura County Flood Control District as a joint venture agency to develop, analyze, evaluate, and implement a feasible seawater intrusion control barrier alternative which will mitigate the problem of seawater intrusion. The need for the involvement of each of these agencies can be illustrated by envisioning a potential project which would consist of Ventura Regional County Sanitation District operating an advanced waste treatment facility; Ventura County Flood Control District operating a seawater intrusion barrier, and United Water Conservation District working with the Flood Control District on the sale of surplus reclaimed water for agricultural reuse in the project area.

"Seawater Intrusion in California: Inventory of Coastal Groundwater Basins," (5) published in 1974, recognized the Oxnard Plain Basin as a "critical intrusion" groundwater basin. The study categorized the Basin as an area with unabated seawater intrusion, and concluded that continued uncontrolled pumping could possibly overdraft the Basin to an extent that irretrievable, irreparable damage would be done, not only to the Oxnard aquifer zone, but also to underlying waterbearing zones. If this were to occur, a significant water resource would be lost resulting in extreme economic consequences.

The loss of pumping wells due to seawater intrusion has necessitated drilling of new wells into deeper aquifer zones, obtaining ground or surface water supplies from inland areas, or using imported water. These options adversely affect water users because of the negative economic impact derived from one or more of the following costs: 1) construction costs of new wells to deeper aquifer zones; 2) increased power costs for pumping water from greater depths; and 3) costs of acquiring more distant water supplies and the necessary distribution system.

Another water resource problem associated with seawater is that the offshore and onshore seawater intruded portions of the Oxnard aquifer zone present a water quality threat to the underlying Mugu aquifer because saltwater in the intruded Oxnard aquifer zone can leak downward to the Mugu aquifer through improperly sealed wells, areas of aquifer mergence, and through aquitards. The total downward leakage of seawater from intruded portions of the Oxnard aquifer zone to the Mugu aquifer was estimated for a dry year (1976) condition to be 12,200 ac-ft/yr. Continued seawater intrusion in the upper aquifer system may also adversely affect the lower aquifer system of the Oxnard Plain. When the Mugu aquifer becomes intruded, either by downward or lateral migration of seawater, the Lower Aquifer System will become intruded in areas of aquifer mergence, or more slowly, by leakage through intervening aquitards. If this occurs, millions of acre-feet of freshwater stored offshore and beneath the Oxnard Plain will not be recoverable.

TREATMENT PROCESSES

The City of Oxnard has contracted with the Ventura Regional County Sanitation District (VRCSD) to operate and maintain the Oxnard Wastewater Treatment Plant (WWTP). In addition, VRCSD is responsible for the source control program for discharges to the Oxnard WWTP.

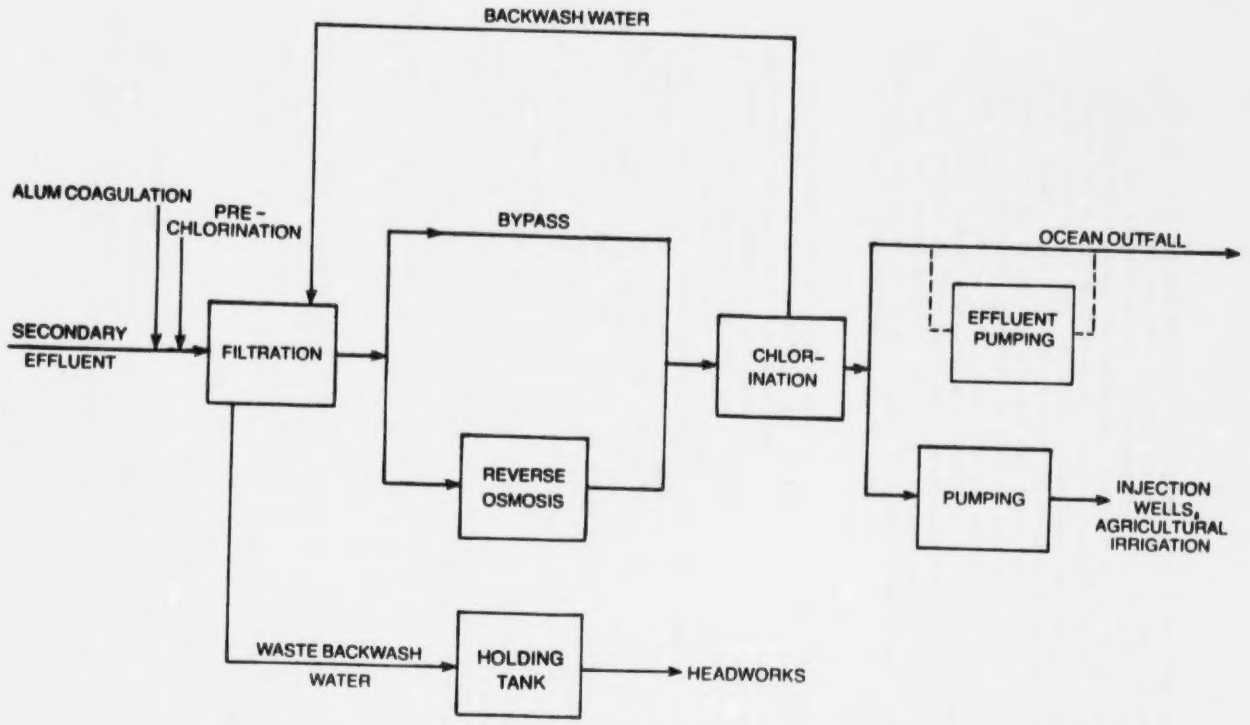
Existing wastewater treatment facilities were constructed under a contract that was completed in late 1973. This system was designed for an average dry weather flow capacity of 25 mgd and has been provided with facilities for grit removal and dewatering, influent pumping, dissolved air flotation/sedimentation, disinfection, and effluent pumping and solids disposal by hauling. The Oxnard WWTP is currently being upgraded from a primary treatment wastewater facility to a secondary treatment wastewater facility (biofiltration) with solids processing and energy recovery by anaerobic digestion, disinfection by chlorination in a new chlorine contact tank, dechlorination, and improved final effluent disposal through modification of the existing ocean outfall.

To produce a reclaimed water of suitable quality for injection, various advanced process combinations are being considered. These include:

1. Multimedia filtration followed by ozonation;
2. Multimedia filtration, reverse osmosis and chlorination;
3. Chlorination, diatomaceous earth filtration and ozonation;
4. Coagulation, multimedia filtration, reverse osmosis and chlorination.

The recommended process train determined to be most cost effective, and technically feasible includes coagulation, multimedia filtration, reverse osmosis and chlorination. An extensive mineral source control program is also being developed. This proposed treatment scheme is illustrated in the following process schematic. To determine the ability of proposed processes to meet quality requirements for injection and public health protection, a pilot program is being developed. Injection water standards and treatment process combinations will conform with current Federal underground injection control programs.

The dual media effluent filters with prechlorination, alum addition, and polymer addition will be employed as part of the recommended plan. Six dual media filters with a surface area of 760 square feet each will be constructed. The filters will be operated at a flow rate of 5.0 gallons per minute per square foot of surface area at design peak dry weather flow. The filter media will be a 48-inch layer of coarse anthracite coal (2.4 to 4.8 millimeter particle size) underlain with 18 inches of fine grain sand (0.9 millimeter effective size). The



PROCESS SCHEMATIC – INJECTION/EXTRACTION WELL SYSTEM SEAWATER INTRUSION CONTROL BARRIER proposed media will allow in-depth filtration and maximize the filter run length. Each filter will be divided into two sections to permit backwashing of each half independently. Backwashing of the filters will consist of an air backwash, air/water backwash, water backwash sequence. The air backwashing will be used to minimize the amount of water adequate for required backwashing. Two low pressure blowers will be required to provide air backwashing with each blower having sufficient capacity to accomplish the air portion of the backwashing sequence. The backwash water will be filtered, chlorinated secondary effluent from the chlorine contact tank. Preliminary analysis indicates that three pumps will be required (two on-line with one standby) to accomplish the water backwashing. The pumps will be located south of the sulfur dioxide flash mixer in the effluent channel of the contact chamber. The backwash rate will range from 10 to 35 gallons per minute per square foot with final rates to be determined during facilities startup.

Water quality considerations for both irrigation and injection require that approximately 46 percent of the reclaimed water be conveyed to reverse osmosis facilities for desalination. Desalination technology, reverse osmosis in particular, is advancing tremendously. Currently, the spiral wound reverse osmosis type unit has been demonstrated to be reliable and effective in numerous locations throughout the world. Filtered secondary effluent will be pressurized to approximately 500 pounds per square inch (psi), provided with the proper chemical pretreatment for pH control and scale prevention, and then passed through cellulose acetate membranes. Product water recovery will be 85 percent of influent with a residual pressure of 30 to 50 psi. The remaining 15 percent of influent will be rejected as brine at a pressure ranging up to 450 psi, with possible energy recovery via the utilization of a turbine generator or pump. The product water will be blended with filtered secondary effluent to provide a reclaimed water which is at least 46 percent (by volume) treated by reverse osmosis. The reclaimed water will then be sufficiently low in dissolved mineral content (less than 1,200 mg/l), even without improvement resulting from this proposed mineral water quality control program, to permit use for agricultural irrigation without crop damage or for injection into the Oxnard aquifer in compliance with regulatory requirements. The brine will be conveyed to the Oxnard WWTP ocean outfall for disposal to the ocean.

The reverse osmosis system will be designed, however, with the assumption that a mineral water quality control program will be developed and vigorously enforced. The reverse osmosis system and the mineral water quality control program are two components of the demineralization methodology.

RECLAIMED WATER CHARACTERISTICS

Wastewater reclamation technology has now advanced to the point where water can be reclaimed to almost any quality desired. In the project area, three vital components are available for the optimal use of reclaimed water for an intrusion control barrier. First, a reliable continuous supply of water is available. Second, the technology exists to produce reclaimed water of suitable quality, and third, and alternative disposal method (existing ocean outfall) can be utilized in the event of plant or unit process upset. Definitive reclaimed water quality requirements for the proposed alternative have yet to be detailed. However, it is expected that such requirements would be attainable with available technology.

Water characteristics which may effect injection capacities and agricultural crops include Langelier Index (scaling), turbidity (clogging), total bacteria (slime growths), oxygen concentration (corrosion), hydrogen sulfide concentration (corrosion), particle size and distribution (clogging) and total dissolved minerals (potential irrigation use).

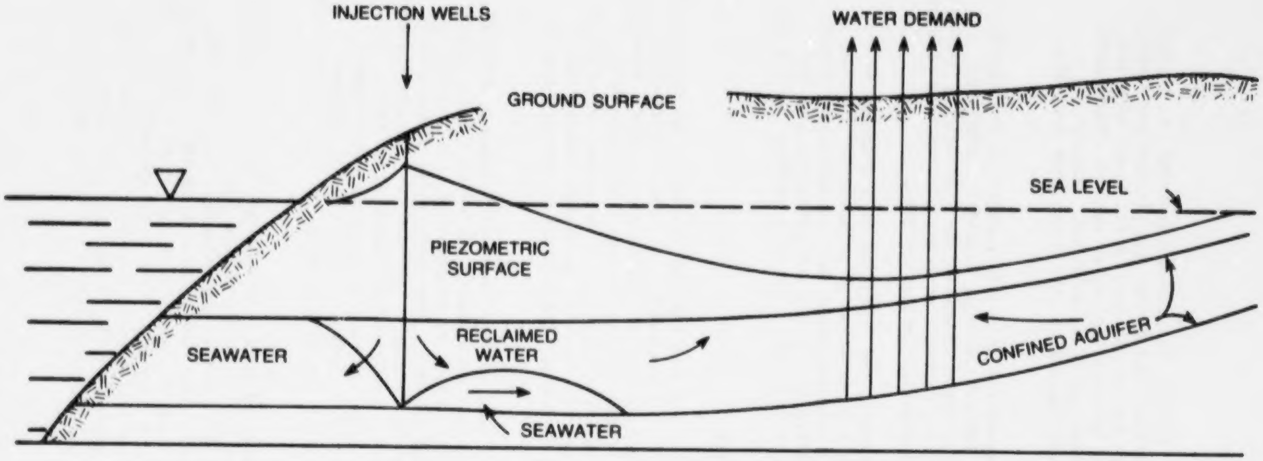
Reclaimed water quality requirements for injection in a groundwater basin must meet with the Basin Plan groundwater objectives. In order to meet these objectives, the reclaimed water must be adequately disinfected and oxidized with concentration levels not exceeding 1200 mg/l total dissolved solids, 150 mg/l chlorides, 600 mg/l sulfate and 1.5 mg/l boron.

INJECTION/EXTRACTION WELL SYSTEM

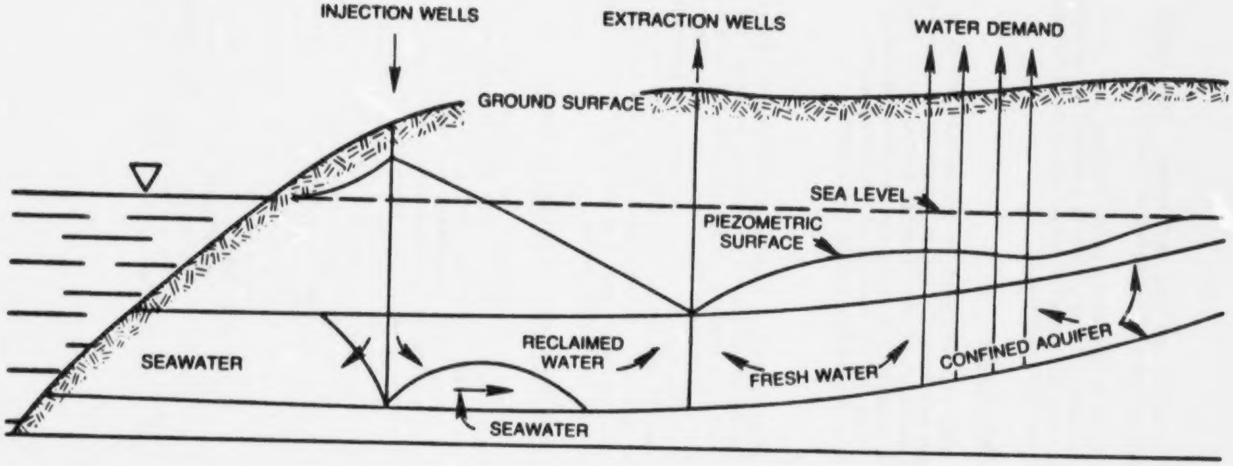
The control barrier alternative involves the utilization of an injection/extraction well system to stabilize and eventually repel the seawater intrusion front from the onshore portion of the Oxnard aquifer. Previous projects specifically in Los Angeles County, Orange County and Palo Alto have been instituted in California to control intrusion of seawater or brackish waters into aquifers utilized for municipal, industrial and agricultural purposes and to protect the remaining storage capacity of the aquifers from degradation.

The West Coast Barrier Project uses an injection well system to control intrusion of seawater into the West Coast Basin, which is a major groundwater reservoir in Los Angeles County. Development of this project began in 1953 and was completed in 1968. The operational components of this project are summarized as follows: The barrier is approximately nine miles long with 94 injection wells and 267 observation wells. Between 1967 and 1969, eleven injection wells required redevelopment and during this period a total of 77,000 ac-ft of filtered Colorado River water was injected. The barrier is successful in halting intrusion in all aquifers. (6)

Seawater intrusion has been averted by a hydraulic barrier system consisting of an extraction/injection system in the Orange County Coastal Barrier Project. Seven extraction wells, approximately two miles from the coast, intercept the seawater and then return it to the ocean through open channels. A freshwater mound is formed by a series of 23 multi-point injection wells into underground aquifers. The injection wells are located on an average of four miles inland. Beginning in October 1976 and continuing through 1977, approximately 13,000 ac-ft of water was injected through the system. The fresh water is a blended combination



HYDROLOGIC CONDITIONS WITH AN INJECTION WELL SYSTEM



HYDROLOGIC CONDITIONS WITH AN INJECTION/EXTRACTION WELL SYSTEM (WITH THE EXTRACTION WELLS INLAND OF THE INJECTION WELLS) of reclaimed water, imported water and deep well water. This system has been an effective method of control of seawater intrusion. (7)

An injection/extraction system is currently being studied in a pilot program in Palo Alto. This system is effectively controlling seawater intrusion, as well as providing mathematical modeling information and data for injection/extraction well system. (8)

Methodology of Injection Well System

An injection well system requires the creation and maintenance of a reclaimed water ridge above sea level to act as a barrier to seawater intrusion. Extraction is not part of this system; consequently frequent well rehabilitation may be necessary to maintain required injection levels. This process provides little control of reclaimed water. The following figure shows a representation of this system.

Methodology of Extraction

Although not physically demonstrated, a pumping trough created by extraction wells is considered to be effective in preventing seawater and reclaimed water movement past the trough. Gradients created by a line of wells constructed parallel to a coast limit seawater intrusion to a stationary wedge inland of the trough. This procedure is technically capable of controlling seawater intrusion and if also effective in preventing reclaimed water passage. Extraction troughs are being effectively used in several areas in South Texas and Wyoming for the control of injection fluids in in-situ mining projects.

Application Of An Injection/Extraction Well System In Oxnard

A potentially feasible alternative as shown in the second figure following would involve an injection/extraction well system with the extraction wells located inland of the injection wells. Using the concept currently being demonstrated in Palo Alto, total management and control of injected reclaimed water would be accomplished. A properly designed and operated injection/extraction well system seawater intrusion control barrier of this configuration would create and maintain a seaward hydraulic gradient that would effectively control seawater intrusion in the Oxnard aquifer as indicated in the following Figure showing barrier alignment. In addition, a significant portion of the extracted water, approximately 70 or 80 percent could be used for agricultural irrigation. The selection of the barrier alignment will be primarily influenced by the extent of the seawater-intrusion front when design of the facilities is inititated as well as site specific geohydrologic characteristics along the intrusion front. In addition to the injection and extraction wells, several monitoring wells will be required if this alternative is implemented. A comprehensive technical description of this alternative will be developed pending approval in concept by the California State Department of Health offices.

Preliminary analysis and evaluation revealed that the injection/extraction well system with the extraction wells inland of the injection wells was the most feasible seawater intrusion control barrier system. This system would optimize and maximize the use of reclaimed water from the Oxnard WWTP as well as mitigate the problem of seawater intrusion in the Oxnard Plain.

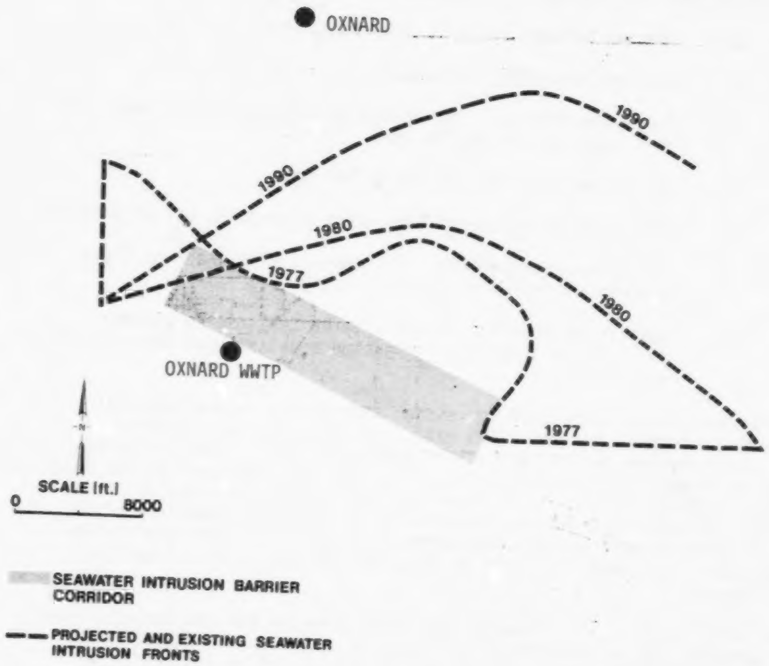
The Seawater Intrusion Control Barrier uses two pipeline systems. An injection/extraction well system with reclaimed water will utilize transmission pipelines from the Oxnard WWTP to the injection wells, in addition to pipelines between extraction wells and selected points of discharge. The extracted reclaimed water may be conveyed to the ocean via existing flood control channels or to the agricultural irrigation pipeline systems.

Several assumptions have been made in the preliminary design of the injection/extraction pipeline system. These assumptions are based on previous studies and available models and are subject to change depending upon the outcome of a demonstration study:

- Spacing between wells is 1000 feet.
- Doublets are 2000 feet apart
- Each injection well is capable of injecting reclaimed water at a pumping rate of 700 gpm.
- Extraction well capability is 900 gpm.
- The pipeline system will be maintained at 75 psi of pressure.
- The extraction pipeline will connect with existing flood control channels for ocean discharge.
- Extraction pipeline layout will be designed to connect with the agricultural irrigation pipeline when water quality is suitable.

These assumptions were used for sizing the reaches in the Seawater Intrusion Control Barrier. The extent of the pipeline system is based on the projected design capacity of the Oxnard WWTP. The following figure shows the proposed boundary lines for the placement of the injection/extraction well system. The injection well system consists of 22 wells with continuous hydraulic connection by an injection pipeline system. An extraction well system consisting of 24 wells has been designated. The system includes 9.6 miles of pipeline ranging in size from 8 to 26 inches.

The effectiveness of a seawater intrusion barrier for the Oxnard Plain Groundwater Basin using reclaimed water is dependent on the control of saline water movement inland and the ability of an extraction well to control the extent of inland movement of the injected reclaimed


OXNARD
1990
1990
1980
1977
1980
1977
OXNARD WWTP
N
SCALE (ft.)
0
8000
SEAWATER INTRUSION BARRIER CORRIDOR
PROJECTED AND EXISTING SEAWATER INTRUSION FRONTS

SEAWATER INTRUSION BARRIER CORRIDOR

water. The Oxnard aquifer is a potable water supply and, as such, is subject to stringent health and quality standards. In the proposed injection/extraction system, the extraction well will remove the injected water that migrates inland, preventing it from intermingling with the Oxnard water supply. The extraction system accomplishes this by creating a pumping trough.

The historical precedence for seawater intrusion control has been demonstrated to be effective in the control of groundwater movement. The injection/extraction system is both theoretically and technically feasible and will provide adequate protection of public health. In addition, through improved design and redevelopment procedures, clogging concerns can be minimized. Injection wells placed a specified distance from the coast would increase the hydraulic pressure of the fresh water, thereby controlling the movement of seawater inland.

When fresh water is injected into an aquifer containing saline water, only slight mixing at the interface occurs. This interface takes the form of an inclined surface with the fresh water overriding the saline water. In the case of the injection of reclaimed water, the interface is similar to injection with fresh water with reclaimed water overriding the saline water. Extraction wells in an injection/extraction system function on the basis of the establishment of a permanent year-round pumping trough.

TECHNICAL ISSUES

Regulatory and technology issues are a significant part of this project. On every level of development of this project, coordination of information effort and decisions is required prior to advancing to the next stage of this project. The major issues that have to be addressed are described and discussed in the following paragraphs.

Currently, the Oxnard aquifer is pumped for both agricultural and domestic water uses. Injection of reclaimed water would be a cause for concern because of the possibility of ingestion by humans. However, all injected reclaimed water is to be extracted by extraction wells for agricultural irrigation or the injected reclaimed water will flow seaward stabilizing, then repelling the intrusion front. The present water quality in the intruded area is not suitable for domestic or agricultural purposes.

The question of the fate of stable organics and viruses in reclaimed water has yet to be resolved. However, if the recommended system is implemented, the critical questions are not relevant. First, the recommended system is hydraulically contained from landward migration. Second, use of the extracted water for agricultural irrigation provides a greater benefit to agriculture as the reclaimed water has received a higher degree of treatment that any scheme involving direct reuse for irrigation. Third, the additional treatment in the aquifer as the water flows to the extraction well has been demonstrated to be effective for virus removal.

The high ratio of reclaimed water recharged to the safe yield of the Oxnard aquifer is also a moot point. As mentioned previously, the Oxnard aquifer is currently overdrafted approximately 8,700 acre-feet per year. The most feasible alternative, aside from alleviating or eliminating the overdraft condition, will be designed to hydraulically separate the potable water portion of the Oxnard aquifer from the seawater/reclaimed water portion of the aquifer.

Discharge and treatment requirements have yet to be developed. Pending detailed review and study of the Palo Alto facility and operation, and of local requirements, technically achievable requirements are expected.

A source control program will be developed in accordance with Department of Health requirements. This source control program will be developed and designed to interface with and supplement the existing program.

A monitoring program will also be developed in accordance with Department of Health requirements and utilizing the experience gained from the operation of the facilities at Palo Alto and Orange County. There exist numerous out of service wells in the intruded portion of the aquifer which may be suitable for monitoring purposes.

Costs

Construction costs developed for this alternative are presented in the following table. These costs are for the advanced treatment system, pipelines, pump stations, wells and land aquisition. The advanced treatment system includes low dose alum coagulation, filtration, and desalting with a reverse osmosis unit at an estimated construction cost of $14,120,000. Pumping station construction costs are $1,096,000. Assuming an average construction cost of approximately $45,000 per well the total cost for this component is $2,073,000. The total construction cost for an injection/extraction well Seawater Intrusion Control Barrier is $19,610,000.

Annual cost of the alternative is based on a 20 year planning period divided by the total reclaimed wastewater volume over the same period. The components of the total annual cost include debt service, operation and maintenance costs, and power costs. The total annual cost for the Seawater Intrusion Control Barrier is approximately $5 million/year.

A breakdown for Federal, State and local costs of the project cost is presented. This table also presents the local unit cost for the alternative based on the local of the project, local debt service, operation and maintenance and power costs. Local unit cost for the Seawater Intrusion Control Barrier alternative is approximately $132/ac-ft.

The monetary costs of a seawater intrusion control barrier are in the range of costs necessary to develop a new water supply. A major factor which will determine the future rate of imported waters is represented

SEAWATER INTRUSION CONTROL BARRIER COSTS

Item	Seawater Intrusion Control Barrier
Construction Costs ($1,000)	
Advanced Treatment	$14,120
Pipeline System	2,321
Pump Stations	1,096
Wells (a)	2,070
Subtotal	19,610
Mineral Water Quality Program	250
Land Acquisition	50
Engineering Cost (b)	5,883
Total Capital Cost	$25,793
Annual Cost ($1,000/yr)	
Debt Service (c)	$ 2,365
O & M	2,585
Power (d)	300
Total Annual Cost	5,250
Total Unit Cost ($/ac-ft) (e)	$ 216
Project Cost ($1,000)	$25,793
Federal Share	22,439
State Share	3,224
Local Share	3,224
Local Annual Cost ($1,000/yr)	
Debt Service (f)	295
O&M	2,585
Power	300
Total Annual	$ 3,180
Local Unit Cost ($/ac-ft)	132

(a) Wells include injection, extraction and monitoring wells.
(b) Includes engineering, administrative, legal and contingency costs at 30 percent of construction cost.
(c) Based on 20 years at 6-5/8% interest rate with capital recovery factor of .0917.
(d) Power for pumping stations.
(e) Based on a flow of 18 mgd.
(f) Capital recovery factor at 20 years and 6-5/8% interest is .0917.

by power costs. Existing long term utility contracts expire in 1983, at that time costs could escalate four to ten times.

Significance of the Use of Reclaimed Wastewater For Control of Seawater Intrusion

There are several advantages to the Seawater Intrusion Control Barrier. A primary benefit would be increased use of groundwater storage. The beneficial effects of the increased use of groundwater storage include: use and storage of surplus water, possible improvement of groundwater quality by recharging with good quality surface water and deference of the need to construct additional surface storage facilities.

Groundwater storage has several advantages when compared with surface storage reservoirs. There is an elimination of evaporation which is a significant fact in surface storage reservoirs. Biological quality problems are minimized because of the absence of light required for aquatic growth. In addition, groundwater storage is less subject to damage through sabotage and spills than with surface storage.

A direct benefit which would be derived from this project is the control of saline water intrusion into the Oxnard aquifer. Since this aquifer is a primary water supply for farming operations on the Oxnard Plain, it has the effect of conserving the fresh water capacity of the Oxnard aquifer, and in some instances improvement of groundwater quality.

The use of reclaimed water as a hydraulic barrier to stabilize and repulse the seawater intrusion front is a system for conserving water resources. Disposal of treated effluent to the ocean is a water wasting method in an area where the water supply is limited.

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A FORMULA FOR SUCCESS

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INTRODUCTION

In this paper the author attempts to generalize the planning experience gained in the Metropolitan Phoenix 208 study in order to make it applicable to other studies which involve planning for wastewater management and reuse. The paper starts with a discussion of the prior planning for both the regional treatment system and the existing wastewater reuse commitments. The author then discusses the planning which was conducted in the 208 program with a focus on the importance of reuse in the overall water resource management of the region, including a discussion of the problems and benefits associated with reuse development in this area. Finally, he concludes with a presentation of a generalized formula for conducting similar planning efforts.

The Phoenix metropolitan area lies in the desert environment of central Arizona. It is at an elevation of approximately 1,000 feet and has a typical desert climate with hot summers and mild winters. Daytime maximum temperatures range from 105 to 115 degrees F in the summer and winter temperatures range from 60 to 70 degrees F. The area receives an average of approximately 8 inches of rainfall per year, and this generally comes as either local thunderstorms in the summer or as a result of frontal Pacific storms in the winter.

The Phoenix area, although settled in the late 1800's, did not grow substantially until the late 1940's. This coincided with the advent of large-scale use of air conditioning. In 1940 the population of the Phoenix metropolitan area was less than 200,000. By 1975, it had grown to 1.2 million and by the year 2000 it is estimated to reach 2.3 million.

PRIOR PLANNING

As was typical of many growing areas, wastewater collection and treatment developed in a haphazard fashion within the Phoenix region. Each of the cities started by dealing with their needs independently. This resulted in a proliferation of treatment facilities which later became nuisances as these once distant cities grew together. In response to these problems the major cities developed a regional system. During the 1960's and 1970's many of the smaller plants were phased out as the Multi-City System was developed. As the communities grew and the trend toward regionalization continued, the Multi-City system expanded at a phenomenal rate. It has grown from a 5 million gallon per day (mgd) facilitiy serving two cities in the early 1960's to a 90 mgd facility currently serving 9 communities, with plans to expand the capacity to 135 mgd by the year 2000. As the growth of the Multi-City system continued, the concentration of greater and greater amounts of wastewater at a single location made the reuse of effluent more attractive. The first agreement for reuse, and the major use of effluent today, was for agriculture. The City of Phoenix is by far the largest contributor of flow to the Multi-City system. Phoenix entered into an agreement with a downstream irrigation district for the use of 30,000 acre feet per year of effluent in exchange for a nominal fee and the settlement of a damage claim resulting from the diversion of surface water by the city. Phoenix also entered into an informal agreement with the State Game and Fish Department for the release of 7,300 acre feet per year to the normally dry Salt River bed in an effort to maintain a portion of the existing streambed habitat.

The largest contract to date involves all of the Multi-City partners, not just the City of Phoenix. This contract calls for the use of up to 140,000 acre feet per year to cool four separate nuclear power reactors located 30 miles west of the Multi-City plant. The contract, signed in 1973, calls for payment of $20 to $30 for each acre foot of effluent used.

The only other major commitments of effluent in the area are from the old City of Phoenix plant. Flow from this plant is committed to meeting the needs of the power plant in the event that the Multi-City plant has insufficient flow. Additionally, up to 20,000 acre feet per year of flow has been committed to another irrigation district subject to first meeting the power plant's needs.

REGIONAL 208 STUDY

In 1972, the Congress of the United States passed Public Law 92-500 which required the development of regional water quality plans under section 208. As a result of this mandate, the local Council of Governments, with the assistance of the U.S. Army Corps of Engineers and the Environmental Protection Agency, initiated 208 planning in the Phoenix area. Despite the prior accomplishments in the development of the Multi-City System, a fresh look at wastewater management in the region was needed. Existing planning and development for the Multi-City System was having difficulty keeping pace with the rapid growth of the area. This was the result of a combination of factors chief among which were: 1) poor operation and maintenance of the existing system, 2) improper functioning of recent additions to the system, and 3) difficulty with meeting the new, more complex planning requirements of PL 92-500.

As the 208 study progressed it became apparent that the reuse of effluent was a focal point in the decision process. Because of the demand for water in the arid Phoenix area better water management is critical to meeting the region's needs. A key aspect of better management is the fuller utilization of existing resources. This can only be accomplished by including water quality considerations in water quantity allocation decisions. By matching the quality of the water used to the needs of the user it is possible to minimize quality constraints on water resource utilization. One result of this would be to eliminate some of the problems which currently exist. An example of such a problem is a community which has drinking water that is unfit for human consumption but is acceptable for agricultural irrigation, while, at the same time, potable water is being used for farming. Unfortunately, matching water quality uses and needs is not a panacea for all water resource management problems in the Phoenix area. Also, the high cost of transporting water serves to limit the applicability of this solution.

Another important mechanism to increase the utilization of the existing resources is to increase the amount of reuse. Once again water quality and matching uses to needs are important in designing the reuse program.

While there were a number of problems associated with reuse of water in the Phoenix area, there were also a number of benefits. On the problem side there were: 1) legal issues such as uncertainty of ownership, potential liability for nuisances and health problems, and prior commitments and rights, 2) increased costs for transportation and treatment, 3) uncertainty about the treatment level necessary to protect some uses, and 4) institutional problems associated with preconceived attitudes of the public and officials, generally low priority among other public concerns, and efforts by individuals to redirect the study to deal with their special interests. On the benefit side there were: 1) economic benefits to be gained from sale of the effluent, from the nutrient value of the effluent and by being able to reduce the treatment or transportation costs, 2) the fact that wastewater effluent represents a dependable and growing supply of water and 3) improvement of water resource management.

While constraints imposed by prior commitments served to limit the present options, the 208 study developed a new awareness of the value of wastewater which will affect planning for future water needs.

A FORMULA FOR SUCCESS

As can be seen from the previous discussion, the Phoenix Area 208 study was no exception to the rule that every study must be tailored to fit the special circumstances of the area in which it is being conducted. The reuse of wastewater was only one element of the overall 208 program. However, if the success of that particular element was to be measured by the immediate changes which resulted then for that part the program must be considered only marginally successful. This is true of almost all planning studies. Today's actions are the result of yesterday's plans and commitments, while today's planning will affect tomorrow's actions. The true success then will be measured by the amount of influence the 208 program has on future decisions and actions.

Besides taking a careful and realistic look at the special problems and constraints which a study faces in a particular area there are a number of other things which are also necessary for the successful completion of a study. The following are some of the more important items for the successful completion of a reuse planning study.

You Need A Mandate

Something has to be driving the study. The stronger this mandate to do the study, the more you will be able to challenge the status quo and the greater will be your freedom to propose changes. This mandate can come from the local, state or federal level or from a combination of the three. In the case of reuse, at the local level the study mandate may stem from a desire: to save money be reducing wastewater treatment or transportation costs, to generate revenue through the sale of effluent or to increase the available water supply through exchange. At the state level the mandate may stem from the need to better manage the existing water resources available within the state. At the federal level the mandate may result from a need to better manage existing water quality funds.

You Need A Forum

You need a forum from which to conduct the study. It is normally preferable to work from an established program rather than to create your own. Reuse studies can be conducted as a part of: 1) PL 92-500 section

201 construction grant programs, 2) PL 92-500 section 208 areawide water quality management programs, 3) existing state water resource management programs, or 4) the U. S. Army Corps of Engineer's Urban Study programs.

You Need Funds

Naturally, you will need money. The sources of funding are quite varied and often involve more than one source. For reuse studies funds typically come from: 1) the local governments or sanitary districts as "in-kind" services to match other funding, as cash matches for other funds or as funds budgeted for the specific study, 2) from the state as manpower assigned to assist the study or as a cash match for other funds, and 3) from the federal government in the form of EPA administered grants or Corps of Engineer's urban study funds.

You Need Time

The amount of time needed will depend on the magnitude of your study which itself depends on the complexity of the problem, the size of the area, the amount of funds available and the number of different interests involved. For a reuse study the necessary time is generally: 1) 6 to 12 months for a single plant, 2) 2 to 3 years for a regional system, and 3) 3 to 4 years for a complex 20 year master plan.

You Need Staff

As is true with every study the quality of the staff will have a major influence on the quality of your study. You can, of course, rely on consultants to augment and assist the staff, however they can not completely replace the staff. Again, the magnitude of the study will be the predominant factor in determining the amount of staff needs. You can use local planning staff for a single plant system, however you will need some regional or state staff to develop any regional system. You also need the support of key local, state and federal agencies throughout the study. This is a very critical item. You must be able to influence these agencies to assign staff to work on the program, often with no financial compensation to the agency. On large studies which involve many agencies this is one of the most difficult things to accomplish. However, leaving a key agency out of the process because they have no one to assign often leads to later problems and possibly even rejection of the final plan.

You Need Public Communication

A strong public participation program geared to the specific needs of the study is essential. The specific needs will vary greatly from study to study but generally will include the following for reuse programs: 1) you need to provide an opportunity for feedback from the public in order to focus the study on the broader community goals and to be able to gauge the support and opposition you will face from the various sectors of the area, 2) you need to educate the public on both the opportunities and needs for reuse within the study area in order to generate support for adoption and implementation of the final plan, and 3) you need to insure that the public's concerns are communicated to the policy and decision makers.

You Need Pluck

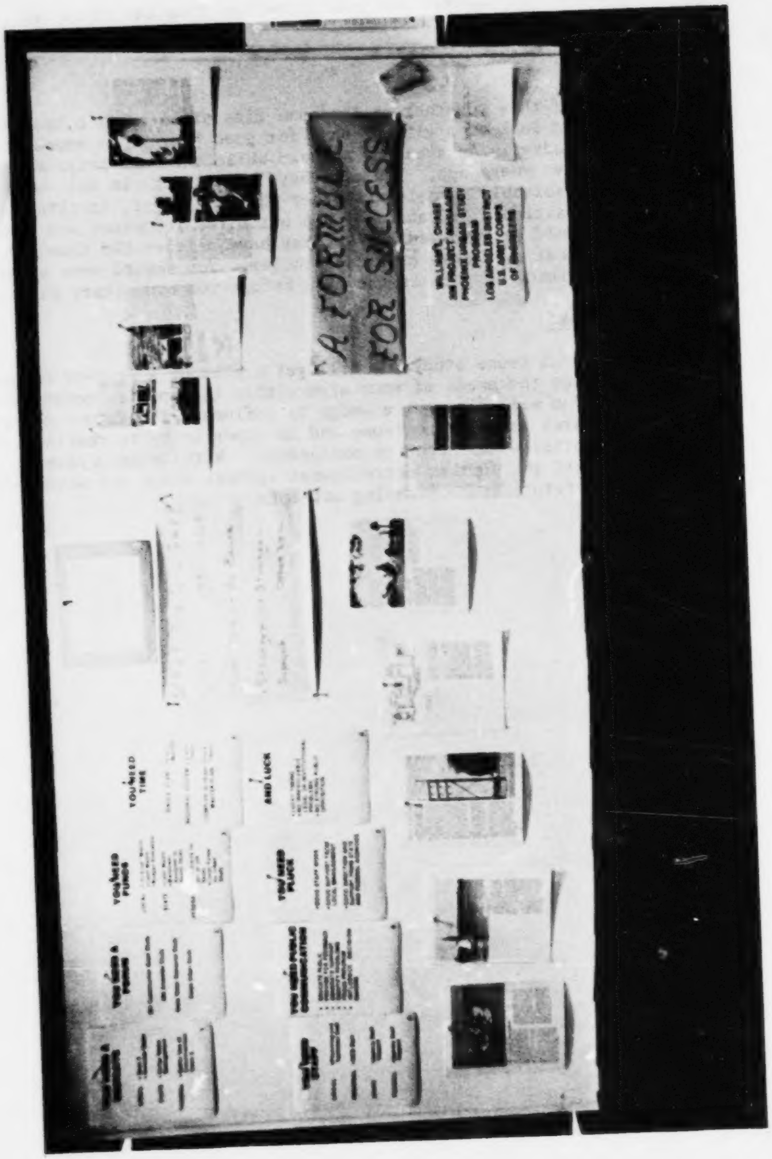
Finally, you need dedicated staff workers, good support from your local policy and decision makers, and good direction from the state and federal agencies who are involved.

And Luck

Bringing all of this together at the same time often takes a healthy measure of good luck or a gifted sense for good timing. A reuse program started today in an area may succeed while the same program may have failed five years ago. You also have to be lucky in not running into any "irresolvable" problems whether they are legal, institutional, or public opposition. Of course, given unlimited resources and time any problem could be resolved but you may have neither the time nor the resources to deal with some critical problem. You should make every effort to determine if this is the case before you even start the study.

What Do You Get?

With a successful reuse study you will get a plan or a project uniquely tailored to meet the needs of your area within the special constraints that exist. You will also get a wedge to influence the future direction of your area relative to reuse and an opportunity to continue to work toward better water resource management. With an unsuccessful porgram you will get further entrenchment against reuse and stronger opposition to future reuse planning attempts.


A FORMULA FOR SUCCESS
WILLIAM L. CHASE
SR PROJECT MANAGER
PHOENIX URBAN STUDY
PROGRAM
LOS ANGELES DISTRICT
U.S. ARMY CORPS
OF ENGINEERS
YOU NEED TIME
AND LUCK
YOU NEED FUNDS
YOU NEED PLUCK
YOU NEED PUBLIC COMMUNICATIONS

AQUACULTURE, WETLANDS AND ECO-SYSTEMS

THE SOLAR AQUACELL AWT LAGOON SYSTEM FOR THE CITY OF HERCULES, CALIFORNIA

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The City of Hercules, a small but fast growing, planned community 30 miles (48 km) northeast of San Francisco, California, is presently completing construction of an innovative Solar AquaCell lagoon wastewater treatment system. This system can produce a range of effluent water quality for multiple reuse options, as well as recycling 100% of the harvested aquatic plants, solids, and digested sludge into reusable by-products within the community. The first phase consists of a 1.5 acre (0.6 ha.) AquaCell and will treat 350,000 gallons per day (1.33 x 10^3 m^3/d) of domestic raw sewage to advanced tertiary quality water. Start-up operations are scheduled for July-August, 1979, approximately 7 months from the start of construction. Upon successful operation of this first demonstration phase, the facility will eventually be expanded to 6 acres (2.4 ha.) of Solar AquaCells capable of treating 2.0 MGD (7.6 x 10^3 m^3/d) of wastewater to meet the growing community's future needs. The purpose of this paper is to summarize the design, treatment objectives, and anticipated operational parameters of this innovative wastewater reclamation facility.

PROJECT BACKGROUND

The City of Hercules' wastewater has been treated to date by the neighboring community of Pinole, but this plant's capacity will soon be exceeded. The major San Francisco Bay area governing agencies have been requiring the regionalizing, treatment upgrading, and discharge of all wastewater flows through large, centralized treatment plants and joint ocean outfalls. However, as part of its overall long term plans for developing an environmentally sound, model community in an area with projected water shortages, the City of Hercules opted to construct its own treatment facility which would: a) produce a higher quality effluent in order to increase their ability to reuse and/or market their reclaimed water to several local industries; b) minimize political/legal conflicts inherent with joint facilities, and allow the community greater freedom over treatment and reuse of their own wastewaters; and c) utilize more natural, ecological processes in order to reduce construction and operations and maintenance costs. The latter was particularly important in the light of accelerating O & M costs of conventional AWT plants. Because the City is financially sound, it could afford to select an unproven, but potentially much more cost effective process not eligible at that time for EPA construction grant funding. Based on Solar AquaSystems' successful pilot demonstration facility results (Ref. 1 & 2) and development of managed aquaculture lagoon system concepts, the City retained the company to examine the feasibility of using ecological methods for wastewater reclamation in the City of Hercules.

The initial feasibility study examined a number of criteria, including the regional NPDES discharge permit requirements, the San Francisco Bay Basin Water Quality Control Plan, existing and potential reuse

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markets, water quality requirements for these reuse markets, environmental impacts, and construction, O & M, and life cycle cost estimates of various alternative treatment processes capable of achieving the required objectives.

RECLAIMED WATER MARKETS & WATER QUALITY REQUIREMENTS

An examination of existing and potential reclaimed water markets in the Hercules area indicated the need for a wide range of effluent water qualities. The environmentally planned city has set aside a high percentage (30%) of its land for greenbelts, allowing 0.5 - 1.5 MGD (1.9×10^3 - 5.7×10^3 m^3/d) for use in local irrigation or sold to surrounding users of irrigation water. This reuse option required only secondary quality effluent.

Two local industries expressed the desire to purchase an additional 0.5 - 1.0 MGD (1.9×10^3 - 3.8×10^3 m^3/d) of water for cooling and wash-down processes if it was "close to the quality of the original tap water". Specific chemical parameter requirements were not known by the industries, but phosphate removal was anticipated to reduce scaling. Finally, two creeks winding through the community, often dry most of the year, are well suited for enhancement and/or incorporation into a marsh-wildfowl sanctuary. Water quality for this application would have to meet strict advanced tertiary standards, if allowed at all by the Regional Water Quality Control Board. Groundwater recharge could also benefit this East Bay area to increase aquifer storage capacity for occasional periods of drought. However, stringent state health regulations for treatment methods (rather than objectives) and as yet unresolved water quality criteria ruled out this alternative for the near future. Any non-recycled water discharged to San Pablo Bay must meet secondary quality (30 ppm BOD and TSS) plus zero chlorine residual. The City was concerned that these discharge requirements could be tightened in the future due to changing environmental and/or government regulatory attitudes.

As a consequence of the identified and projected requirements for a variety of effluent qualities, plus the realization that any or all these water quality or volume reuse needs could frequently change over the life cycle of any facility, it was clear that the most optimal treatment alternative must maximize treatment flexibility without greatly increasing capital or O & M costs.

THE SOLAR AQUACELL TREATMENT PROCESS

The treatment process selected consists of an innovative, aerated lagoon design known as the Solar AquaCell System. It has been specifically developed to combine the best features of low construction and operation costs of aerated, earthen lagoons, with the control, reliability, reduced land requirements, and advanced treatment capability of conventional, higher technology treatment plants. It incorporates the following main components, as shown in Fig. 1:

1) greenhouse-type solar covers installed over 8 feet (2.4 m) deep lagoons for collecting solar heat and maintaining higher year-round operating temperatures, preventing evaporative losses (with resultant TDS increases), and allowing year-round high growth rates of floating aquatic plants;

2) floating aquatic plants (water hyacinths and duckweeds) to shade out undesired suspended algae, while reducing BOD, suspended solids, dissolved nutrients, and absorbing and metabolizing organic chemicals

and heavy metals;

3) submerged, high surface area bio-film substrates ("Activated Bio-Web Substrates") to increase surface area for bacterial, protozoan and invertebrate food web productivity, thereby greatly accelerating treatment rates and reducing land area requirements;

4) dual submerged and surface aeration systems for partial mixing and oxygenating the relatively high loading rate ponds;

5) hardy, invertebrate grazing organisms (amphipods, ostracods, gastropods, etc.) for consuming, metabolizing, and bio-concentrating particulate waste, detritus, and bacterial biomass through the food web, to be harvested together with the aquatic plants.

FACILITY DESIGN

The Hercules facility is designed as a three phase lagoon system consisting of an anaerobic AquaCell (two-stages), followed by a facultative AquaCell, and a large third phase aerobic AquaCell (Figure 2 and Table 1). In the ultimate facility (2.0 MGD or 7.6×10^3 m^3/d), three independent facultative/aerobic cell units will be operated in parallel to allow the City flexibility to select and more efficiently meet changing water discharge or reuse needs. For the first demonstration phase scheduled for start-up in August, only about one-half of Solar AquaCell "A" is being constructed. It will still be divided into three cells containing all components with similar retention times, as indicated in Table 1.

Pretreatment will consist only of grinding (comminutor) in order to minimize clogging problems during periodic removal of sludge from the anaerobic cell. The two stage anaerobic AquaCells are designed to provide 12-20 hour total retention time, with the first stage designed to operate primarily as the sedimentation and acid fermentation stage. The second stage contains vertically hanging, self-cleaning bio-film substrates to improve treatment and methane fermentation. This will allow more control, stability and treatment efficiency of the anaerobic process. Both anaerobic ponds will be covered with floating synthetic rubber covers with gas collection channels. The black covers will function as solar heat absorbers and insulate against heat losses, in order to maintain higher operating temperatures and improve winter period treatment. The combination of aerobic with anaerobic ponds has the further advantage of balancing out seasonal differences in treatment efficiency between the ponds. The anaerobic phase will function better during the winter, due to improved sedimentation and reduced sludge digestion and thereby counteract the slightly decreased operating efficiency of the aerobic AquaCells during winter. During the summer periods, the reverse trend will occur. The increased sludge digestion in the anaerobic pond will decrease its effluent quality, while the facultative and aerobic AquaCells will produce higher quality effluent due to higher operating temperatures and increased aquatic plant and bacterial metabolism and growth.

The second cell (facultative) and third cell (aerobic and aquatic plants) in each series are combined in the same earthen pond, with a rubber curtain wall hydraulically separating and providing a channel for the facultative treatment area. The rubber curtain wall is integrated with the greenhouse columns for cost savings. The facultative stage is designed for approximately 24 hour retention time, and contains the diffused aeration and Activated Bio-Web substrate components. Its function is threefold: 1) to reduce BOD by use of higher aeration than will be maintained in the aerobic AquaCell stage; 2) to reduce BOD by means of coagulation and sedimentation of suspended solids via the Bio-Web Substrate mechansim, and 3) to nitrify ammonia in order to reduce toxicity in the following aerobic stage. The facultative pond will not contain water hyacinths or duckweeds, in order to maximize oxygen exchange through the surface. Diffuser pipers at the influent and effluent ends of the facultative and aerobic ponds minimize short circuiting problems.

In the final aerobic Solar AquaCell stage, oxygen levels will range from 2 ppm at the influent to 6 ppm or greater at the effluent end during the 5 day retention time. Water hyacinths and duckweeds will be cultured over the entire water surface of this stage in order to prevent growth of algae, to assist the Bio-Web reduction of BOD, S.S., total nitrogen and phosphates, and to produce a valuable by-product. Multiple overflow screens will reduce escape of detritivore invertebrates, fish or plants.

The only post-treatment processes needed for secondary quality effluent will be disinfection. Ozone was selected over chlorine, in spite of its slightly increased costs, for several reasons. Dechlorination would be necessary for bay discharge, thus increasing total costs of chlorine usage. For tertiary reuse needs, chlorine is less desirable since it is known to increase levels of potentially toxic chlorinated hydrocarbons, and does not provide the additional oxidation and back-up treatment capability of ozone.

For tertiary effluent needs, sand filtration before ozone treatment will assure removal of any remaining suspended solids to levels below 3.0 ppm. Although the Solar AquaCell pilot facility has demonstrated reliable reduction of TSS to levels of 0 - 10 ppm within four days, the escaping micro-invertebrates, plant root hairs, and occasional re-suspended organic detritus must be screened or filtered out for certain reuse applications.

ADVANTAGES OF THE MANAGED ECOSYSTEM PROCESS TO THE COMMUNITY

The advantages to the community of this particular application of the Solar AquaCell process over other alternatives examined are as follows:

Production of Variable Effluent Quality for Different Reuse Needs

With the ultimate 2.0 MGD (7.6 x 10^3 m^3/d) facility, the three separate aerobic lagoons (Fig. 2), will be operated in parallel to allow the City flexibility to select for and more efficiently meet changing water reuse and/or discharge criteria. By varying the wastewater flow to each of the three AquaCells, retention times can be proportionately increased to produce a higher quality effluent, or decreased to produce a secondary quality effluent for irrigation or bay discharge. For example, if a future market exists for 1.0 MGD (3.8 x 10^3 m^3/d) of high quality water (e.g. BOD, T.S.S. less than 2.0 ppm, total nitrogen less than 5.0 ppm, ammonia less than 0.1 ppm) then 50% of the 2.0 MGD (7.6 x 10^3 m^3/d) flow can be diverted through 2 of the 3 lagoons at an average retention of ten days, while the remaining 1.0 MGD (3.8 x 10^3 m^3/d) is treated to secondary quality in the third lagoon with a retention time of about three days.

Lower Construction Expense

Cost analysis indicated a 2.0 MGD (7.6 x 10^3 m^3/d) AquaCell system with retention time to produce an advanced tertiary quality water could be constructed for about the same cost ($3.5 million) as a 2.0 MGD (7.6×10^3 m^3/d) expansion of the existing activated sludge facility at neighboring Pinole. In addition to producing only secondary quality effluent with limited reuse options and value, the Pinole alternative would have required much greater pumping distances and potential regulatory problems for reuse or sale of the water by Hercules.

The high construction cost of conventional, high technology AWT facilities ($4 to $6 per gallon [3.8 litres] of treatment capacity), compared to the Solar AquaCell Process (average $2 per gallon [3.8 litres] of treatment capacity), ruled them out of consideration by the City.

Lower Operation & Maintenance Expense

The low energy requirements of the aquaculture lagoon process (about 15 hp/MGD [15.2 hp(m)/3.8×10^3 m^3/d] for secondary, or 25 hp/MGD [25.4 hp(M)/3.8×10^3 m^3/d] for advanced tertiary), and greatly reduced maintenance, sludge handling and labor expenses should reduce annual O & M costs to about 50% less than projected 20 year costs for the alternative activated sludge system, even though a much higher quality water will be produced. This cost savings differential is expected to increase as energy costs continue to escalate. Energy requirements are low due to the use of photosynthetic and anaerobic biological processes, low mixing requirements, and high water surface area per MGD (3.8×10^3 m^3/d) to increase passive oxygen exchange. Personnel needs will be limited primarily to harvesting and composting activities, requiring only one to two full-time operators per 1-2 MGD (3.8 - 7.6×10^3 m^3/d) for AWT. Total O & M costs are projected to average 30-40¢/1,000 gallons (3,785 litres) to achieve advanced tertiary quality effluent, and 20¢/1,000 gallons (3,785 litres) for secondary at the 2.0 MGD (7.6×10^3 m^3/d) capacity.

Revenues from Reclaimed Water

Economic projections were made to estimate the potential dollar value of reclaimed water to the community. Assuming sale of only 50% of the water at 50% of the projected future value of tap water, the economic benefit from sale or use of the reclaimed water to replace imported supplies could, in itself, pay for a major portion of the facility's annual O & M costs.

Improved Solids Handling & Reuse

The aquatic plants harvested on a regular basis can be reused by conversion to either methane gas, high quality organic compost, or sold as an animal feed supplement. Hercules preferred reuse of the plants in the form of compost, needed in large quantities for landscaping purposes during development of their community over the next 20 years. An additional advantage with composting is derived by combining the digested sludge removed periodically from the first stage anaerobic AquaCell with the harvested plants. By composting both forms of wastewater solids together for recycling, the sludge takes on a more attractive marketing form and in turn further enriches the nutrient value of the plant compost.

In this manner, 100% of all solids can be recycled directly within the community instead of paying for hauling to out-of-town dump sites, as is currently done with most neighboring conventional treatment plants. Total solids handling volumes will also be reduced compared to alternative treatment methods. For example, final digested solids volumes from conventional activated sludge plants average 360 cu.ft. (10.2 m^3) per day per MGD (3.8 x 10 m^3/d) (Ref. 3). In contrast, projected total solids volumes from composted hyacinths or duckweeds, and anaerobic cell sludge will average only 100 (2.8 m^3), 26 (0.7 m^3), and 67 (1.9 m^3) cu. ft./day/MGD (3.8 x 10 m^3/d), respectively. Further, the relative simplicity and stability of the composting and anaerobic pond digestion processes, in comparison to conventional primary treatment and high rate anaerobic digestion methods, greatly reduces operator skill requirements, odors, and/or process failures common with conventional solids handling methods.

Improved Process Stability and Reliability

The process has been designed as a multiple series of cells that can operate in any combination of parallel or series flow, allowing shutdown, independent performance monitoring, or adjustment of any component stage without seriously disrupting overall treatment. The three cell flow sequence through anaerobic (primary), facultative (secondary), to final aerobic (tertiary) lagoons (see Table 2), with hardy water hyacinths and duckweeds only in the last cell, serves to both buffer and rapidly dilute any shock loads of toxic wastes otherwise capable of affecting the bacterial or plant components. The additional holding capacity within the pond berm freeboard provides for 1-2 day reserve retention time in the event of temporary mechanical failure. Due to the poor reliability of conventional AWT plants, as shown by EPA (Refs. 4 and 5), this was an important criterion for the City.

Small Land Area Requirements

The Bio Web Substrates, aeration, and greenhouse components allow a great reduction of retention time necessary to achieve AWT. In comparison to the 20-40 days with hyacinth only ponds (Ref. 6), or the 60 - 120 days of algae lagoons, the AquaCell process requires only 5-10 days. For the City of Hercules climatic zone, it is projected that about 3 acres (1.2 ha.) of AquaCells (3 day retention time) are required to treat 2.0 MGD (7.6 x 10^3 m^3/d) to secondary quality. For various levels of AWT, 5-8 acres (2.0 - 3.2 ha.) of lagoons (5-10 days per 2.0 MGD [7.6 x 10^3 m^3/d]) are necessary. Additional area for the pond covers, access roads, post-treatment, compost area, operator building, etc., bringing the total to 10 acres (4.05 ha.) for treating 2.0 MGD (7.6 x 10^3 m^3/d) to advanced tertiary. By comparison, most conventional secondary treatment facilities treating 2.0 MGD (7.6 x 10^3 m^3/d) need similar land areas of 6-12 acres (2.4 - 4.9 ha.), yet have less conservative total retention times of only 6-8 hours.

Elimination of Odors

A common problem with location of either conventional lagoon or high technology treatment processes is offensive odors. In the SAS pilot system to date, the combination of sealed, floating rubber covers on the anaerobic AquaCell, continuous aeration of the facultative and aerobic AquaCells, plus the greenhouse pond cover has served to eliminate odors. For the Hercules facility, an odor control aeration chamber (10 minute retention time) between the anaerobic and facultative cells will provide additional back up odor control capability.

Low Ozone Requirements for Disinfection

Due to the projected low levels of suspended solids, BOD and COD in the effluent, ozone dosages and attendent energy requirements are estimated to be about 50% less than otherwise required for treating secondary quality effluent.

Low Chemical Requirements for Phosphate Removal

The only chemical not readily removed by this controlled aquaculture process is phosphate. This is due to the much higher demand for nitrogen than phosphorus (16:1 ratio) by growing plants, bacteria, or invertebrates. An average of only 1.0 ppm/4 days is expected to be removed. However, due again to the low BOD, T.S.S., and ammonia effluent levels, only about 30% of the lime or other phosphate precipitating chemicals normally required will be needed for a potential user requiring phosphate free reclaimed water.

PROJECT DESIGN, MANAGEMENT, AND AWARD

The Solar AquaCell Treatment Facility has been designed by Solar AquaSystems, Inc., Encinitas, California, together with KCA Engineers, Inc., San Francisco, who provided engineering on basic treatment facility components. The City of Hercules was recently honored with the State of California, Governor's Award for the most appropriate technology project of the year.

Further information may be obtained from Solar AquaSystems, (P.O. Box 88, Encinitas, CA 92024, [714] 753-0649), or Ralph Snyder, City Manager, P.O. Box 156, Hercules, CA 94547.

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TABLE 1

SUMMARY OF UNIT PROCESSES FOR THE CITY OF HERCULES WASTEWATER RECLAMATION FACILITY

STAGE	DESCRIPTION/FUNCTION	RETENTION TIME[1]
Headworks	Comminuter with bar screen bypass. Gravity Flow.	---
Cell 1 (Primary)	Anaerobic AquaCell with floating black cover & bio-film substrates for sedimentation, sludge digestion, and methane production.	0.75 days (Solids = 6-12 mos.)
Cell 2 (Secondary)	Facultative AquaCell lagoon with solar pond cover, mild aeration, fixed-film, "Bio-Web Substrates", and no floating aquatic plants. Process provides oxidation, coagulation, sedimentation, nitrification, denitrification, and flow equalization.	0.75 days
Cell 3 (Advanced Tertiary)	Aerobic AquaCell lagoon with greenhouse cover, mild aeration, fixed-film, "Bio-Web Substrates", floating aquatic plants (hyacinths and duckweeds), and detritivore invertebrates. Process provides further oxidation, coagulation, sedimentation, nitrification, denitrification, and flow equalization, as well as direct absorption of nutrients, mineral solids, and any remaining heavy metals or chlorinated hydrocarbons.	5 days
Final Filtration	Sand Filtration - single media sand filtration @ 2-3 gpm/sq.ft. - with dual filters, air mixing, and auto backwash.	10-20 min.
Disinfection	Ozone with chlorine back up.	10-15 min.
Clearwell	Clearwell & effluent pumping station	1-2 hrs.
Composter	Controlled environment biomass composter - All harvested biomass (primarily water hyacinths) and digested sludge from primary AquaCell will be composted in a solar heated, automated building to allow for total recycling of all solids.	14-20 days (Solids)

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1) Note: Retention times will vary depending on effluent objectives. Above times are for achieving advanced tertiary effluent. Total retention time for secondary quality can be reduced to 2-3 days, and the sand filter bypassed.

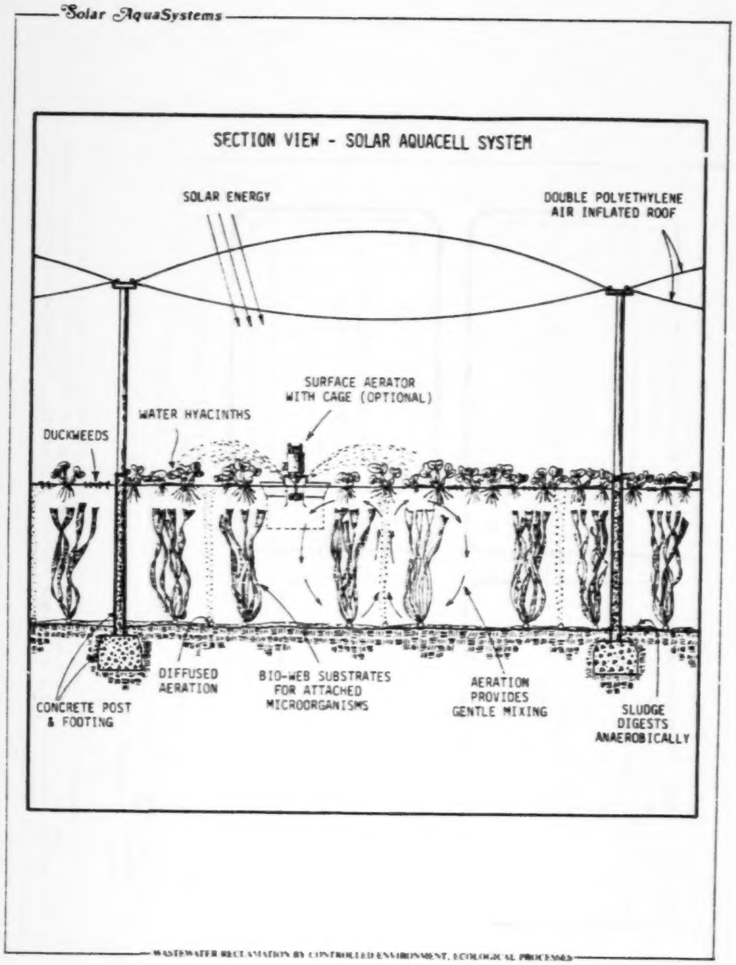
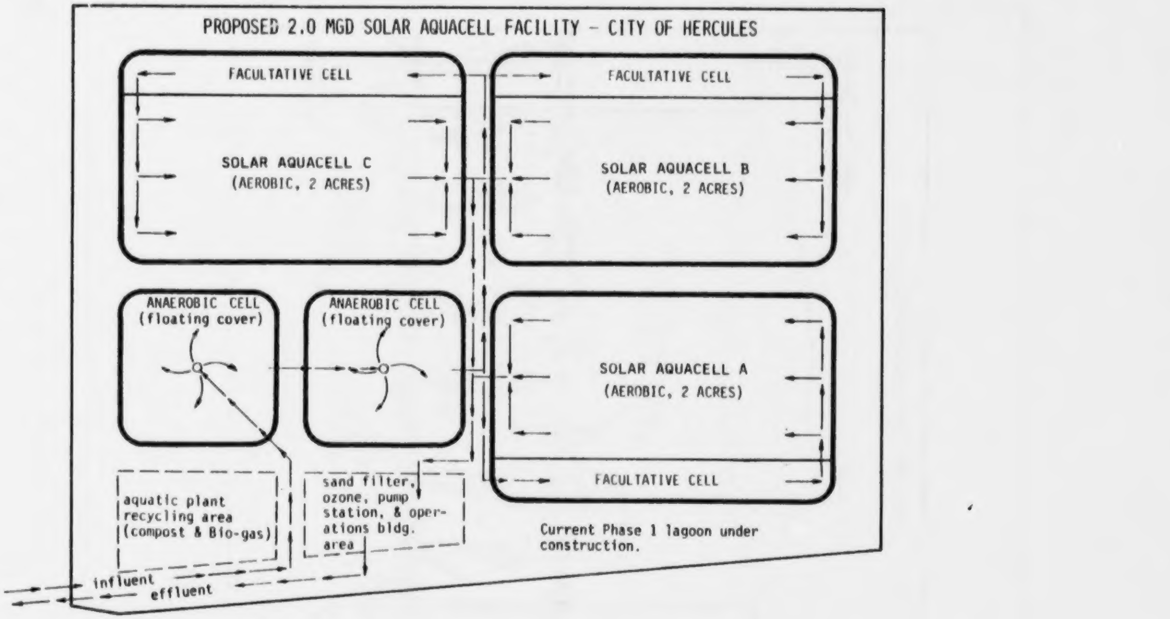

Solar AquaSystems
SECTION VIEW - SOLAR AQUACELL SYSTEM
SOLAR ENERGY
DOUBLE POLYETHYLENE AIR INFLATED ROOF
SURFACE AERATOR WITH CAGE (OPTIONAL)
WATER HYACINTHS
DUCKWEEDS
DIFFUSED AERATION
BIO-WEB SUBSTRATES FOR ATTACHED MICROORGANISMS
AERATION PROVIDES GENTLE MIXING
CONCRETE POST & FOOTING
SLUDGE DIGESTS ANAEROBICALLY
WASTEWATER RECLAMATION BY CONTROLLED ENVIRONMENT, ECOLOGICAL PROCESSES

FIGURE 1



Plan View of the proposed 2.0 MGD Solar AquaCell Lagoon Treatment Facility for the City of Hercules, California. Each AquaCell will be 2.0 acres (6 acres total). The 0.35 MGD demonstration phase currently under construction consists of a 1.5 acre AquaCell system with anaerobic, facultative and aerobic stages. approximately ⅓ of AquaCell #1.

FIGURE 2

RECYCLE AND SAN DIEGO

R. W. KING
Director, Water Utilities Department
City of San Diego, California

San Diego, California, located in the most southwestern part of the United States, has a population around 800,000. The regional population is one and one half million. Tijuana, Mexico, our next door neighbor, has a population of 800,000 so the entire area has about two and a third million inhabitants which is expected to double in the next twenty years. While these data are not significant in themselves they become dramatic when one realizes that San Diego's rainfall is only enough for 35,000 people. San Diego, in spite of the fact it has a seemingly endless shoreline with its ocean, bays and harbor, is very much a desert area. There are lots of problems. The main problem is finding a new water supply.

The Water Utilities Department for the City of San Diego is a combined water and sewer agency for the City and also has the Metropolitan Sewerage System. "Metro" serves 16 surrounding cities and districts as well as taking sewage from Tijuana, Mexico on an emergency basis. Our sewage treatment is a primary plant with discharge two and a half miles out in the ocean at a depth of 220 feet from a multiport "Y" shaped diffuser system. Our digested sludge is air dried, mixed with sand and seaweed and used in our parks as a soil improver.

Because we are a combined water and sewer agency we are inclined to examine whatever problems we have from that combined viewpoint. Thus, in searching for a new water supply we looked at these alternates: (a) import fresh water, (b) desalt ocean water, or (c) recycle effluent.

From the 1968 U.S. Water Resources Council, California by the year 2000 will have a total demand for water of 121 billion gallons per day (BGD) and a supply of 69 BGD -- obviously San Diego can expect no importing help from California. The ocean has 30,000 ppm of salt while sewage has only 2,000. Thus sewage recycle is simpler and easier to treat than to desalt the ocean -- we are looking therefore to recycling effluent as a strong possibility for that new water source.

Our ocean view from the Metro plant on Pt. Loma out over our outfall encompasses many activities of recreation, food and plant production on and under water. The area is rich in kelp -- a local company harvests kelp on a regular basis. Fishing continues the year 'round along with sailing, power boating, surfing, diving and harvesting of abalone and spiny lobster. Mountains of data, research studies, monitoring and computer analyses, have confirmed not only no adverse effects of our effluent on the area but that there has been an enhancement of the marine life. Public Law 92-500 mandates that all cities have secondary treatment plants whether they are needed or not -- and that is our second problem.

We therefore have two problems: Our short water supply caused by nature and a sewage problem caused by legislation and regulation -- neither of which can be superseded by the other. Both need addressing with equal intensity in providing a combined water and sewer service to the public, and expressed in terms the public can understand -- from the general public's viewpoint and not our own.

We analyzed supplying a potable water and collecting and treating the sewage on the basis of energy demands, wastes produced and their ultimate destiny along with costs in a conceptualized manner for any city anywhere. The findings, as they later were detailed for our area, were provacative for we found water considerations have enormous impacts on sewage; and sewage considerations have enormous impacts on water -- making us realize our traditional way in San Diego of studying and regulating water separately from sewage can give misleading results.

This is evidenced most clearly, for example, in the usual method of costing treatment in terms of dollars per million gallons. In our study and for the same treatment, we used, of course, the same cost per million gallons for each of various combined water and sewer alternatives. When this was incorporated into a monthly bill the homeowner would pay for their combined water and sewer service, however, the range for such bills for some systems was as much as ten times others. We are saying quite clearly that the expressed customary view of not using tertiary treatment because it's too expensive or takes too much electricity which is the conclusion from the usual method of costing treatment is not in all cases correct for us. A city like San Diego, that imports almost all of its water can have cost savings on the water side that offset costs of advanced treatment on the sewer side. We recognize that all the sewage that can be recycled reduces the need to import a like quantity of water.

We found, also, from our study that such societal considerations as life style (apartment versus single family) or lawn watering affects water and sewer costs and flows far more significantly than do technological considerations. For example, a system that totally optimizes full recycle with changed lifestyles could serve the same population with one-tenth the water supply of a contemporary system.

Our work suggested also that the definition of the elusive word "environment" needs clarification. Environment has been used for limited activities such as in front of one's house as in replacing or adding a water or sewer line. When done so, little is achieved. But when environment is defined in a less restricted sense as the region where people invade the natural state (for water supply) to where people reenter it (sewage disposal) then environment achieves a value capable of quantifying impacts. It is over these parameters, water supply to sewage disposal, that our analyses was based and from this perspective genuine impacts on our natural resources can be made.

San Diego needs recycling all the way to the potable supply as contrasted to usual reclamation projects for irrigation or industrial use. When we add up all irrigation uses in San Diego for golf courses, highway interchanges and public parks the amount is 2%. For industry, the use is 5-7%. Thus our total need for customary reuse is less than 10% -- hardly enough to relieve our depleting natural resources. In previous cases where we did use secondary effluent to water golf courses and other areas, the high salt content in the effluent killed the grass. For these reasons we discontinued any further consideration of secondary effluent for reclamation and concentrated all our efforts into full recycle back to the potable supply. There is nothing unilateral or the maverick in our approach -- we are in constant touch with and receive guidance from our regulatory agencies who have encouraged us to continue our efforts.

Some of the conceptual alternates studied had upstream recycle facilities, that is, plants located in the peripheral area surrounding the City. In such plants we used a "bio-lake" concept wherein a lake receives secondary effluent. The lake is oxygenated, stocked with fish and plant life for nutrient removal, and has a two year holding time. Water from the lake is then sent through a reverse osmosis unit for salt control and returned to the drinking water system. Such water with sewer concepts use substantially less electricity and are less costly than the standard straight through legal systems.

We have had considerable experience in operating reverse osmosis (R/O) units. Over the past ten years we developed a process with the tubular R/O taking raw sewage and making it into near drinking quality water in one pass. The State of California Department of Water Resources (DWR) conducted a study of polio virus removal with our R/O unit and concluded the unit did remove the virus. Although we previously used the R/O unit to make industrial quality water for our boilers we now use the unit to grow grass for the stadium for athletic events such as football and baseball.

Without our realizing it at the time, Dr. Alice Jokela, a professor of one of our Universities, recognized the bio-lake idea as being akin to her interest in aquaculture, subsequently leading us to the work being done by Dr. Bill Wolverton of NASA who was using water hyacinths in sewage treatment. Dr. Jokela's interest was further enhanced by a local company, Solar Aquafarms, who built a 1400 gallons per day (gpd) hyacinth facility for growing shrimp and other fish life as a byproduct of treating sewage. It was argued that digested bio mass from hyacinths could be used for methane and electricity production. The concept of a treatment system that could also produce a water supply, along with food and electrical production became an idea too tempting to turn down -- it thus appeared we were on the track of a solution to the survival of our City in this natural desert.

We felt likewise with our R/O experience on raw sewage, we could polish the clear effluent from hyacinths by using spiral R/O or ultra filtration which in either case requires substantially less electricity than tubular. If that could work then we really would make a contribution to the industry.

Taking these possibilities and integrating them with the reality of the need for relatively large land areas for sewage reclamation, our lower elevation to Tijuana, Mexico, and Tijuana's lack of a sewage plant, we then offered the idea for an international treating facility located about a mile north of the border using the resource recovery concept as a starting base. Such a location for the moment accommodates the different problems facing us and also keeps open several options for later course corrections. With such an arrangement we provide for not only our need for sewage treatment but for those of Tijuana's as well. Also, the hyacinth, R/O, carbon absorption and lake treatment will provide water supply and electrical energy. This concept recognizes sewage as a valuable resource by converting the ingredients back into a productive use rather than concentrating them to possibly toxic levels as do the conventional treatment systems. Such a recovery system as we are proposing interestingly enough, merely reproduces the process nature has been using all along to clean up liquid wastes.

To follow the destiny of all ingredients through this system we made a chemical balance, tracing the loadings in pounds of heavy metals, BOD, suspended and dissolved solids, grease and oil, etc., through each step of the various processes including, of course, in the effluent but more importantly in the removed flows as well. Most of our work revolved around suitable disposition of the removed items to ensure that the ultimate destiny was non-toxic. In doing so we identified our drinking water as the source of 48% of TDS and 7% of the heavy metals. Flowing through the hyacinth beds, we estimate, a reduction in pounds of about 90% for heavy metals and BOD and 19% in TDS occurs, although there is some argument available to raise TDS removal up to 40%.

Armed with an extract of the creditable data available suggesting we had a worthy project for more serious investigation, we went to our City Council requesting their approval of our efforts in seeking grant funding of $3 1/2 million dollars for a one million gallon per day plant and a three year program to test the feasibility of using water hyacinths for the treatment of sewage. Approval was received in the Spring of 1977 and $500,000 set aside as our portion of this project to be done under Section 201 of PL 92-500. Our application went to the State of California Water Resource Control Board (SWRCB) who assigned several Ph'D's the job of preparing the work plan. A recent announcement from the SWRCB stated this project should be underway in 1979 with results coming in during 1980. This project also includes digestion of the harvested hyacinth so it will be possible to quantify methane and therefore electrical production as well. It is our hope this project will answer once and for all the question of the worthiness of hyacinths as a treatment for sewage.

Since getting into the subject of aquaculture and water hyacinths, we've been introduced to people similarly oriented and have learned a great number of other aquatic plants exist, but not investigated, suggesting there may be a whole series of yet undiscovered weeds with possibly greater potential than hyacinths. If so, and if our project is successful, then perhaps we have participated in opening doors to a whole new approach to water restoration. Besides that, and by using the best of old and new technologies, a combined water and sewer system could be developed solving our water supply and sewage treatment problems, simultaneously bolstering our natural resources and providing an adequate water and sewer system for the projected growth of the area.

RECLAMATION AND REUSE OF WASTEWATER
IN THE
SUISUN MARSH, CALIFORNIA

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INTRODUCTION

The Waste Water Reclamation and Reuse Pilot Demonstration Program for the Suisun Marsh began in 1972 with the objective of demonstrating the compatibility of beneficial reuse and treatment of municipal wastewater with marsh management. The emphasis was on using existing techniques of marsh management to maintain a desirable waterfowl habitat and agriculture irrigation in the Suisun Marsh, utilizing wastewater as a supply.

The program was a joint venture among the United States Bureau of Reclamation, the Solano Irrigation District, and the City of Fairfield. The City of Fairfield was interested in the treatment and disposal of wastewater in such a manner as to be economical and minimize adverse effects on the environment, the Solano Irrigation District was interested in demonstrating the reuse of wastewater for agriculture use, and the Bureau of Reclamation was interested in the use of wastewater to maintain present waterfowl benefits in the Suisun Marsh insofar as these benefits would be reduced by future project operations. The joint venture was designed to serve the needs of all three parties.

DESCRIPTION OF THE AREA

The Suisun Marsh is comprised of 85,000 acres (34,000 hectares) of land and water located approximately midway between the cities of Sacramento and San Francisco (figure 1). About 55,000 acres (22,300 hectares) are leveed or partially leveed island areas lying below 6 feet (2 meters) elevation and about 30,000 acres (11,700 hectares) are water surface. About 45,000 acres (18,000 hectares) are in privately owned duck clubs and 10,000 acres (4,300 hectares) in publicly managed waterfowl areas. The Marsh is about 20 miles (32 kilometers) long and 12 miles (19 kilometers) wide, and is the largest single brackish water marsh in the Continental United States.

It is a vital segment of winter habitat for waterfowl in the Pacific Flyway, with as many as 500,000 to 750,000 birds using it at any one time. It is particularly important in October, November and December when flooding of waterfowl areas in the Sacramento and San Joaquin Valleys is limited to prevent agriculture crop damage.

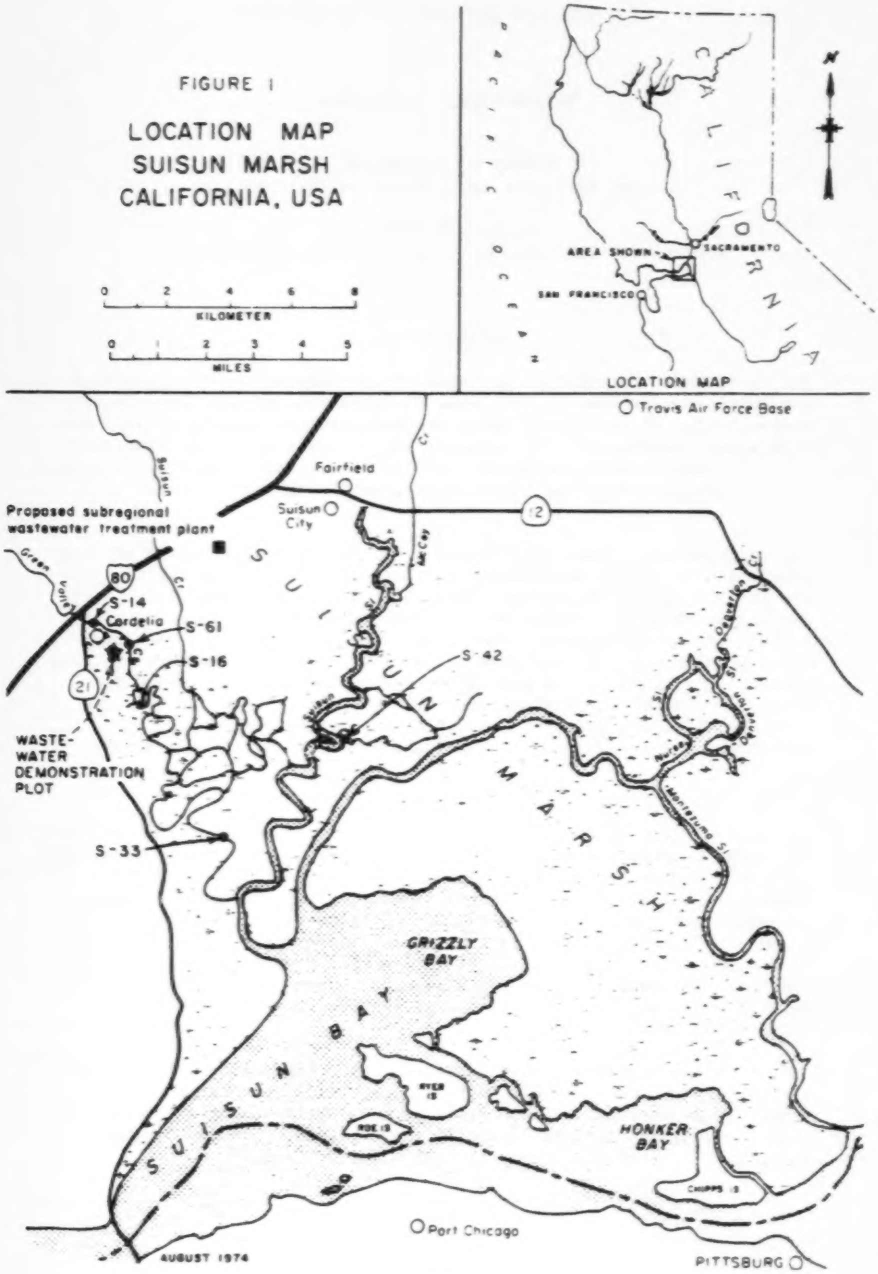


FIGURE 1

LOCATION MAP
SUISUN MARSH
CALIFORNIA, USA

Summers in the Marsh are warm and dry, and the winters are mild and wet. Temperature exceeds 90 degrees F. (32° C) about 10 days of each summer and are below freezing about 10 days during the winter. Normal precipitation is about 22 inches (56 centimeters) of rain which occurs mostly from November through March.

Soils in the Marsh consist primarily of poorly drained black peaty muck and mottled gray clay. Vegetative cover consists of over 177 plant species with saltgrass, pickleweed, alkali bulrush, brass buttons and fathen occupying 61 percent of the land area.

DESCRIPTION OF THE STUDY

Study Objectives

The overall objective of the study was to demonstrate the compatibility of beneficial reclamation and reuse of municipal wastewater in the Suisun Marsh. Specific study objectives were as follows:

1. Determine the potential for beneficial use of treated municipal and industrial wastewater in the Suisun Marsh, and the appropriate marsh management practices and application rates for such beneficial use.

2. Determine the changes in constituent concentrations that take place during use of the wastewater.

3. Determine the need for treatment of resulting return flows from irrigation and marshland uses in order to render the flows acceptable for year-round discharge to the sloughs of the marsh. The San Francisco Bay Regional Water Quality Control Board in 1972 had suggested a limit of 3 mg/L total nitrogen in wastewater discharges to the main water bodies of the northern part of the San Francisco Bay, including Suisun Bay and the Suisun Marsh.

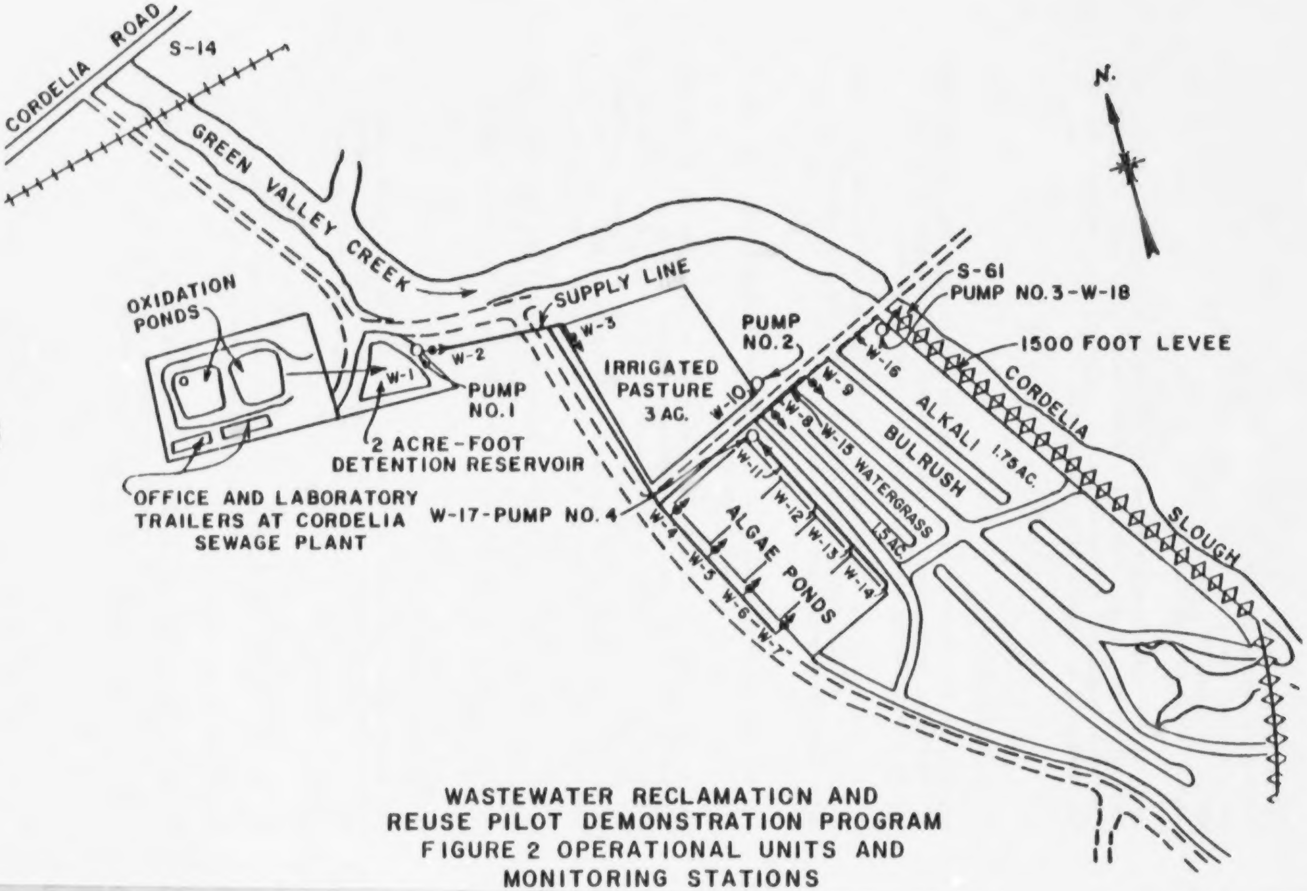
4. Determine in a preliminary manner the method and technical feasibility of incorporating future wastewater flows from Fairfield and areas adjacent to the Suisun Marsh and other areas into marsh management programs.

Field Facilities

The field facilities were located on a 30 acre (12.1 hectares) plot of land on the northwest corner of the Suisun Marsh, near the town of Cordelia and the City of Fairfield's Cordelia waste treatment facility. Specific features are as follows (figure 2):

1. Cordelia Waste Treatment Facility. A 0.25 mgd (100 m^3/d) secondary treatment facility consisting of two aerated oxidation ponds, a multi-media filter and chlorination ponds provided wastewater for operation of the project.

2. Detention Reservoir. A 2 acre foot (2,467 m^3) capacity detention reservoir to provide storage and regulation of sewage flows and elimination of chlorine residual from the treated water.



WASTEWATER RECLAMATION AND
REUSE PILOT DEMONSTRATION PROGRAM
FIGURE 2 OPERATIONAL UNITS AND
MONITORING STATIONS

3. Tile Drained Irrigation Pasture. A three acre (1.2 hectare) sprinkler irrigated and tile drained plot used for growing pasture and forage crops.

4. Marsh Ponds. A two acre (0.81 hectare) area divided into four ponds and operated either seasonally or all year at water depth of 2 feet (0.61 meter). The ponds were operated to store water to aid rapid flooding of the Irrigated Marsh Plots, provide nitrogen removal through algal growth and uptake and denitrification and resting areas for waterfowl.

5. Irrigated Marsh Ponds. A 10 acre (4.0 hectares) area was subdivided to provide two marsh plots about 1.5 acres (0.61 hectare) each. Alkali bulrush was to be established in one plot, and watergrass was planted in the other. The ponds were flooded at a depth of 0.5 to 1 foot (0.15 to 0.30 meter) from October to May with draining and drying from June through September.

Study Plan

Irrigated Pasture. The three acre irrigated plot was planted to permanent pasture two years and rotated seasonally one year with oats and vetch as a winter and spring hay crop and Sudangrass for hay during the summer. The pasture was heavily irrigated to determine the capacity of the soil to remove nitrogen and phosphorus from the wastewater. The seasonal crops were irrigated according to plant requirements for water. Analyses of irrigation supply and subsurface drainage were used to determine changes in water quality.

Marsh Ponds. The marsh ponds were operated to provide nitrogen removal, water supply for flooding the irrigated grass marsh ponds and treatment of water to supplement the other two features in order to provide adequate nitrogen removal at all times of the year.

Irrigated Marsh Ponds. The irrigated grass ponds were operated seasonally to produce waterfowl forage. Generally, flooding was from October through May; however, in 1977 the watergrass pond was flooded during the summer. During 1977 and 1978, all the water supply to the watergrass pond was combined outflow from the marsh (algae) ponds and the water supply to the bulrush pond was a combination of tile drainage from the pasture and wastewater from the detention reservoir with a TDS of 3,000 to 5,000 mg/L. All water samples were collected between 8 and 9 A.M. standard or daylight time. All field analyses were performed in a laboratory in the office trailer and samples prepared, frozen and transported to Sacramento for chemical analyses.

STUDY RESULTS

The Cordelia waste treatment facility produced secondary quality effluent that was delivered directly to the detention reservoir. The quality of wastewater supplied to the study units from the reservoir (Station W2) is presented in figures 3 and 4.

Water temperature varied seasonally from less than 5 degrees C in January to about 20 degrees C in June, July and August. The summer of 1977 and winter of 1978 were exceptional with maximum water temperature in July of only 15 degrees C and 10 degrees C in January.

Dissolved oxygen was 6 milligrams per liter or more except for December when it decreased to 4 mg/L. This was due to treatment plant upset that was caused by a gasoline leakage at a nearby service station that drained into the sewer line and high rainfall that extended the infiltration into the sewer line into January.

Total dissolved solids (TDS) averaged about 750 milligrams per liter, and chloride averaged 200 milligrams per liter throughout the study.

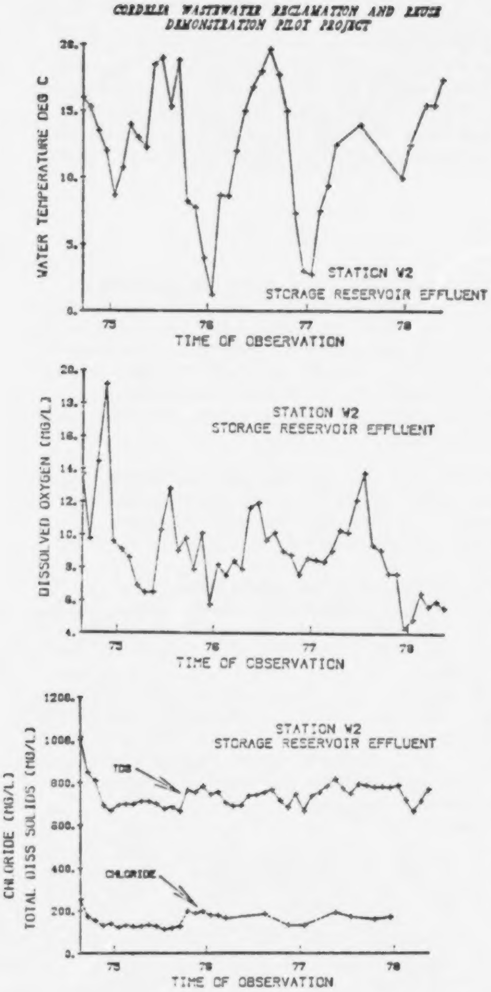
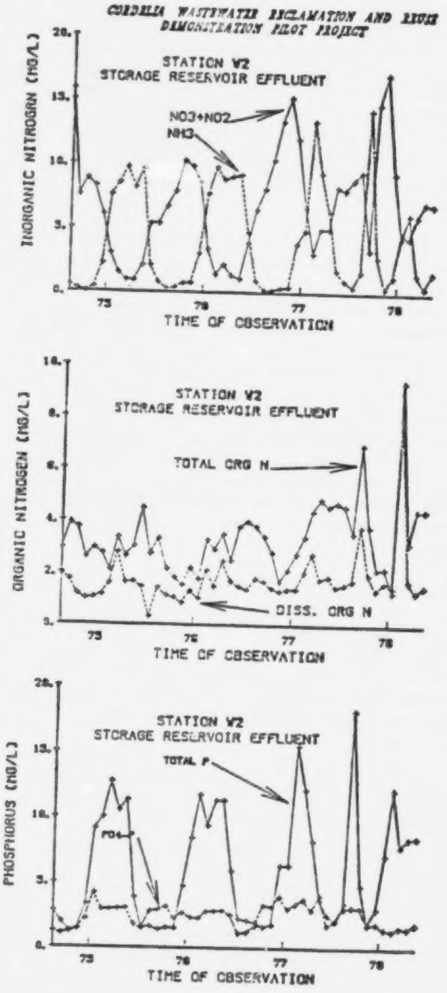


Figure 3. Detention Reservoir Water Quality



Inorganic nitrogen was measured as ammonia nitrogen (NH_3-N) and nitrate plus nitrite nitrogen (NO_3+NO_2-N).

These two constituents varied inversely seasonally, with the concentration of ammonia averaging 10 mg/L during the winter and less than 1 mg/L during the summer, while NO_3+NO_2-N averaged 10 mg/L during the summer and 2 mg/L during the winter. Seasonally, the transition period was about one month behind the seasonal temperature changes.

Dissolved organic nitrogen was usually near 2 mg/L; however, total organic nitrogen at station W2 varied from 2 to more than 4 mg/L according to the growth of algae in the detention reservoir.

Total phosphorus seemed to have a seasonal variation, with concentrations as high as 10 to 15 mg/L. However, much of the year the total was about the same as orthophosphorus (PO_4-P) which averaged 3 to 4 mg/L. On two occasions ortho was greater than total phosphorus, and the discrepancy was attributed to unresolved interferences to the analytical test.

Figure 4. Detention Reservoir Nitrogen and Phosphorus

Irrigated Pasture

The three acre agriculture plot was planted with a pasture grass seed mixture suited to the area in October 1974 and sprinkler irrigated to a stand. No additional wastewater was applied until after the first crop of hay was harvested in June 1975. Thereafter, from June 1975 through October 1976 the pasture was sprinkler irrigated with wastewater at the highest rate possible, supplementary to rainfall and not causing water ponding on the surface of the soil. The rate of irrigation was from 9 to 17 inches (23 to 42 cm) per month in the summer and was reduced to zero during winter dormancy. In November 1976 the plot was disked, and in December planted to a mixture of oats and vetch. From 2 to 8 inches of wastewater was applied to supplement rainfall in February, March and April of 1977. After harvesting in May, the plot was planted to Sudangrass in June and irrigated at a rate of 8 inches of water per month from June through September 1977. The production of hay from all three crops was above the average for the area.

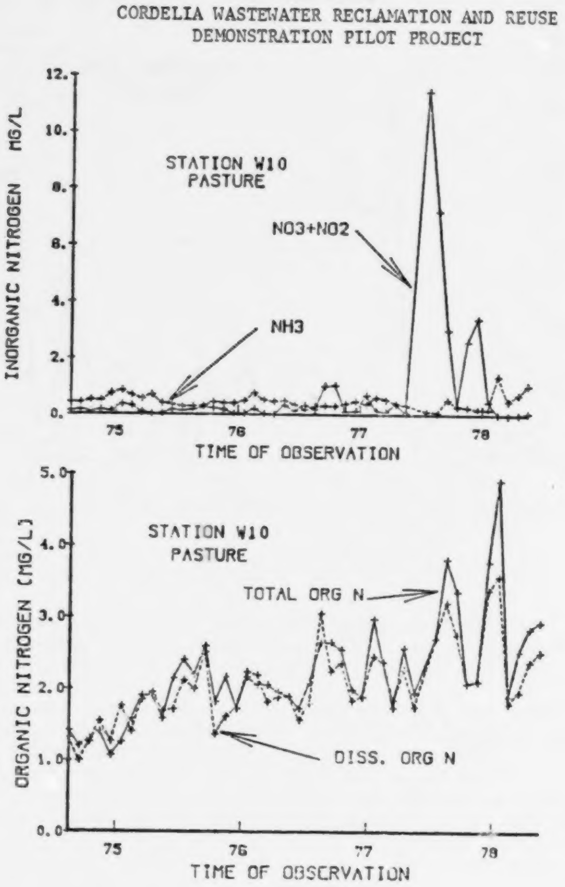
Nitrogen. Nitrate and ammonia nitrogen in the tile drainage was less than one milligram per liter during more than two years of the study (figure 5). However, during July, August and September of 1977 nitrate plus nitrite nitrogen increased to as high as 12 milligrams per liter. The wastewater from the detention reservoir contained from 10 to 15 milligrams per liter total inorganic nitrogen (see figure 4). The soil appeared to have been an efficient media for removing nitrogen in irrigation supply even with irrigation rates of more than 12 inches per month. However, from July to September and in December 1977, nitrate in the drainage increased to more than 3 mg/L and was nearly 12 mg/L N in July. This was during a period of moderate to light irrigation and when the plot was planted to Sudangrass. One explanation is that Sudangrass was a relatively low nitrogen user, and the moderate rate of irrigation provided for an aerobic environment in the soil, releasing nitrate into water percolating through the soil.

Organic nitrogen gradually increased from less than 1.5 mg/L in 1974 to 3 to 4 mg/L in late 1977, compared to 2 to 4 mg/L total organic and 1 to 2 mg/L dissolved organic nitrogen in the wastewater supply. Essentially all the organic nitrogen in the pasture drainage was dissolved, whereas in the irrigation supply part of the total was dissolved organic nitrogen. There were some unresolved interferences in the chemical analysis for organic nitrogen that produced results of dissolved organic greater than total organic nitrogen.

Phosphorus. Soil is known to be a sink for phosphorus and test results were true to form in the pasture drainage. Total phosphorus was generally less than 1 milligram per liter (figure 6), except for two occasions, one in 1975 and another in 1978, when total phosphorus increased to two milligrams per liter. The cause of the 1975 increase was unknown, but the second increase followed by about three months a large spill of detergent from a bulk carrier at a nearby truck washing facility. Ortho phosphorus was generally about one half of total phosphorus and phosphorus in the irrigation supply averaged about 2.5 milligrams per liter in the ortho form and about 7 milligrams per liter total phosphorus.

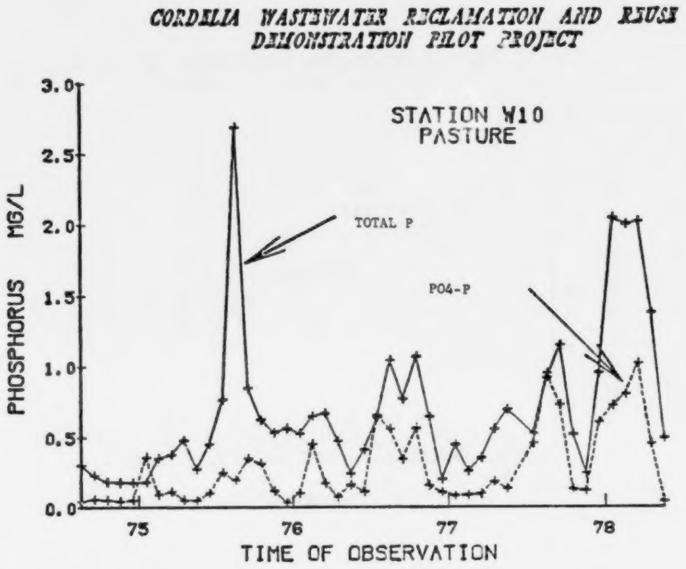
Dissolved Oxygen

Dissolved oxygen in the tile drainage ranged from near zero to 5 milligrams per liter during the study and is typical of tile drainage



CORDELIA WASTEWATER RECLAMATION AND REUSE
DEMONSTRATION PILOT PROJECT

Figure 5. Nitrogen in Pasture Drainage



(figure 7). If dissolved oxygen were deemed a problem, then some method of reaeration such as short term ponding or low pressure aeration would have to be utilized for discharge to waterways in the marsh.

Salinity. There was a dramatic long term change in total dissolved salts in the drainage. In 1974 the TDS of drainage from the pasture averaged 20,000 milligrams per liter. A gradual decline began in 1975, and by late 1977 the TDS of the drainage had declined to 5,000 mg/L. Tile drainage demonstrated that the use of a drainage system is effective in reducing and controlling the accumulation of salt in the agriculture soils, including areas where the ground surface is less than four feet above sea level.

Marsh Ponds

The four marsh (algae) ponds were operated primarily to supplement the treatment and use of water by the pasture and the irrigated marsh (grass) ponds. They were operated in pairs, ponds 1 and 2 at one-half the flow rate of ponds 3 and 4. Pond 1 was operated at a water depth of 1 foot (0.33 m) and the others at a water depth of 2 feet (0.67 m). Due to lack of water resulting from water conservation efforts during the drought, operation of ponds 1 and 2 was terminated in May of 1977.

Water flow to ponds 3 and 4 averaged 30,000 gallons per day, a rate of 5.5 acre feet per acre per month (2.760 m^3/ha/mo), and ponds 1 and 2 at 2.75 acre feet per month (1.380 m^3/ha/mo), except for April, May and September of 1975 when the flow rate to all four ponds was as much as double the average for the rest of the study.

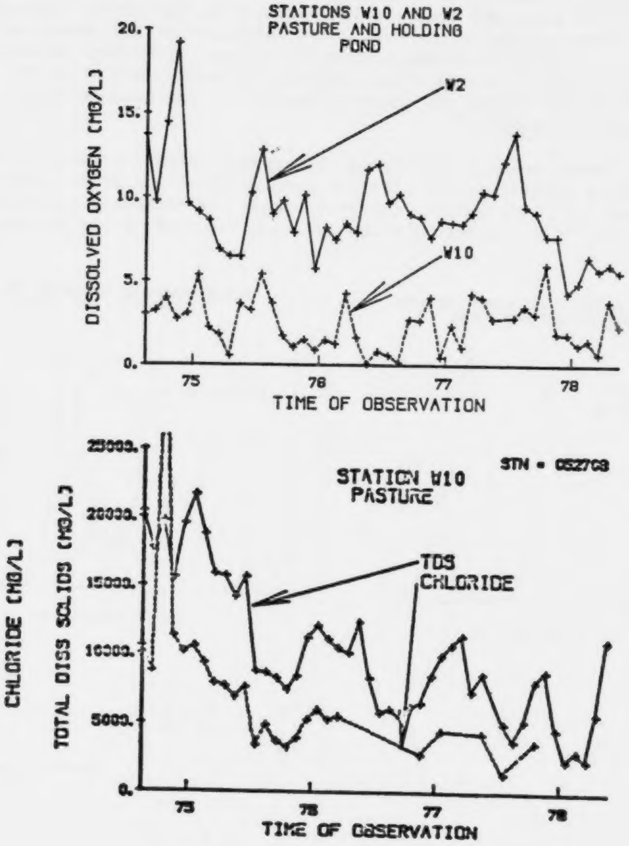


Figure 7. TDS and Dissolved Oxygen in Pasture Drainage.

Nitrogen. There was considerable seasonal variation in the concentration of ammonia and nitrate nitrogen in the algae marsh ponds, as high as 8 milligrams per liter during the winter and less than 2 milligrams per liter during the summer (figure 8). There also was considerable variation in concentration of ammonia and nitrate plus nitrite that was due to the effect of the winter to summer ammonia and nitrate changes in the wastewater supply and the effect of temperature on the biological activity of algae and denitrifying bacteria in the ponds. Nitrate generally increased during the fall, then decreased to low levels as ammonia in the supply increased during the winter, while both nitrate and ammonia decreased to low levels during the summer soon after nitrate plus nitrite became the dominant species of inorganic nitrogen in the wastewater supply.

During the summer months, May through September, total inorganic nitrogen averaged 2 milligrams per liter in the low-flow-rate ponds and 4 to 5 milligrams per liter in the high-rate ponds, and increased to about 8 milligrams per liter in both the low and high flow rate ponds during

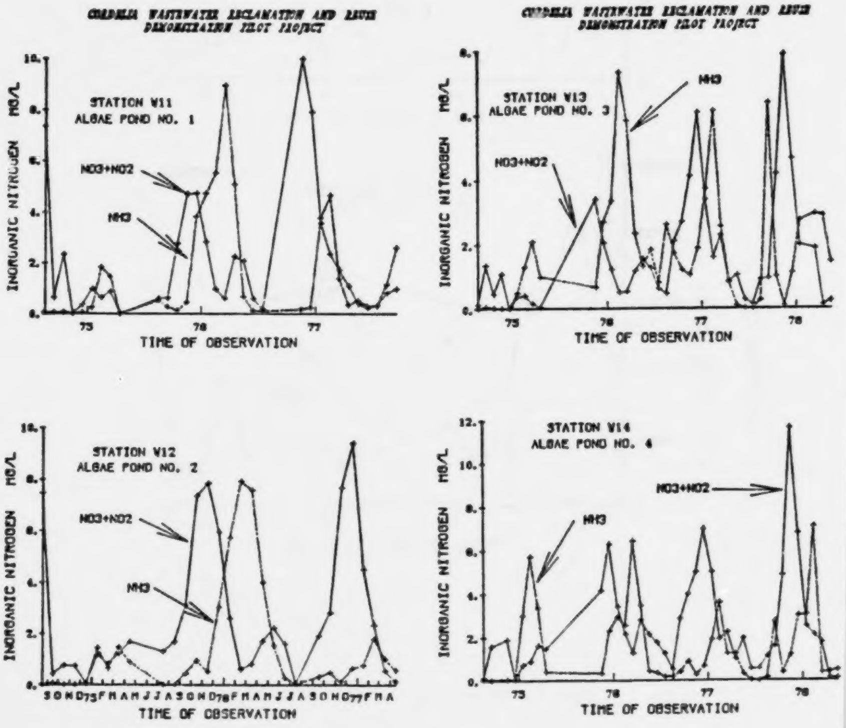


Figure 8. Marsh Pond Inorganic Nitrogen

the winter. There appeared to be essentially no difference in the performance of Algae Pond 1 at one foot (0.33 m) water depth and Algae Pond 2 operated at the same flow rate but a water depth of 2 feet (0.67 m). This is in agreement with the hypothesis that most denitrification in algae ponds occurs at or near the soil water interface and therefore is dependent on surface area, not water volume.

Dissolved organic nitrogen averaged 1.5 to 2 milligrams per liter in both the high and low flow rate ponds (figure 9); however, total organic nitrogen varied from only slightly higher than dissolved organic nitrogen during the winter to 6 to 8 milligrams per liter during the warm weather months of the year, indicating a biomass of algae containing 4 to 6 milligrams per liter of organic nitrogen.

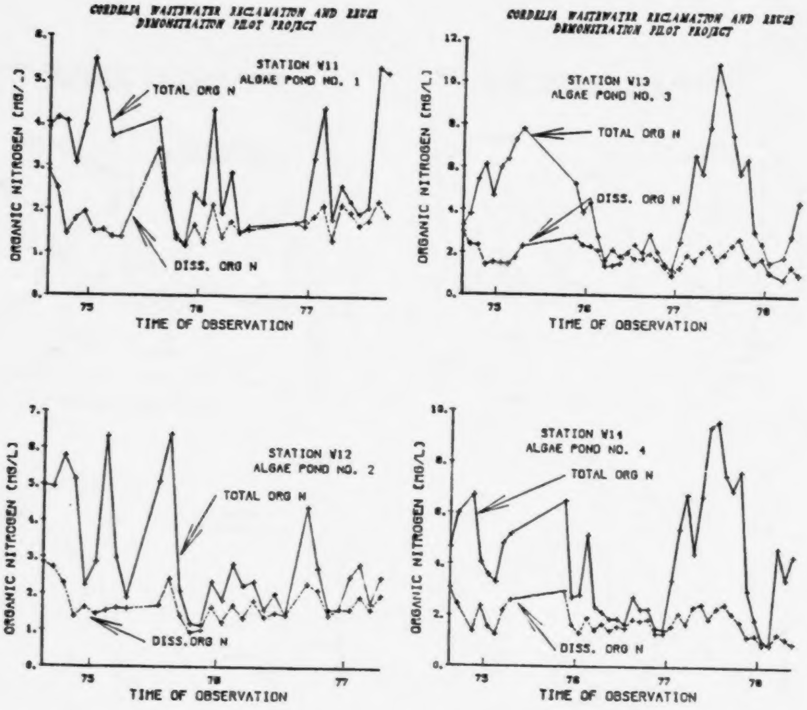


Figure 9. Marsh Pond Organic Nitrogen

Phosphorus. Dissolved ortho phosphorus varied from about 1 to 3 milligrams per liter in outflow from the algae ponds, about the same or higher than concentration in the supply water. However, total phosphorus varied from 2 to almost 7 milligrams per liter in pond outflow compared to from 2 to over 10 milligrams per liter in the supply water (figure 10). This indicated a considerable breakdown to ortho or algal uptake of the poly and other forms of phosphorus that occur in municipal wastewater. Overall, the reduction in phosphorus amounted to from 30 to 50 percent of the total in the influent and was assumed to be from a combination of algal growth and precipitation of phosphorus which settled to the bottom of the ponds. There was not a great difference between the high and low flow rate ponds, another indication that algal growth and uptake of phosphorus was an important factor in phosphorus removal in the marsh ponds.

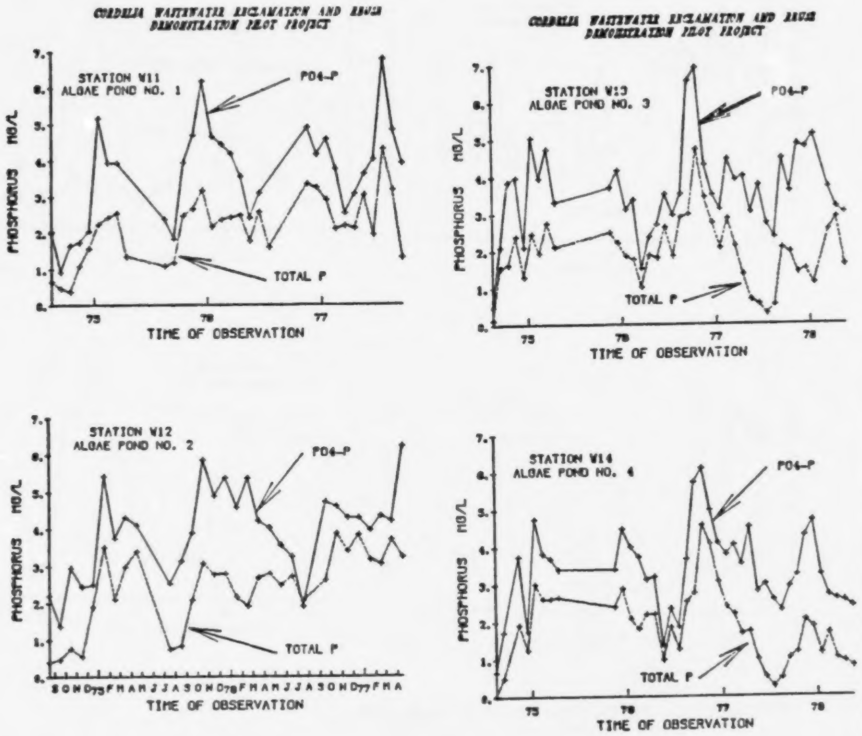


Figure 10. Marsh Pond Phosphorus

Dissolved Oxygen. Dissolved oxygen varied from as low as 2 milligrams per liter to more than 14 milligrams per liter with average D.O. from 6 to 8 mg/L (figure 11). Low dissolved oxygen levels occurred during the summer or fall months and was always associated with the die-off of filamentous algae and pondweeds. Whenever the population was predominately free floating green algae species, dissolved oxygen was 6 to 8 milligrams per liter or higher. It was concluded that summertime operation of shallow marsh ponds was not practical for treatment and discharge of wastewater into waterways of the marsh.

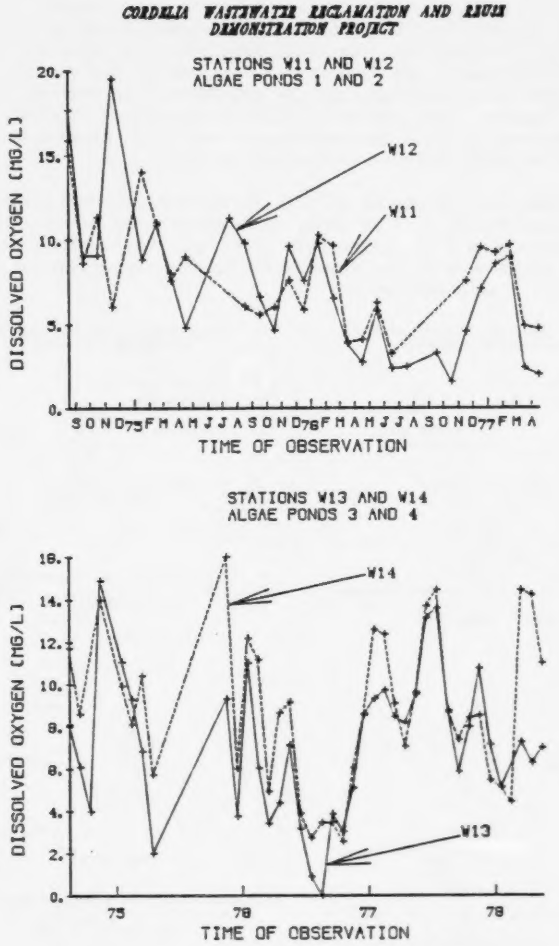


Figure 11. Marsh Pond Dissolved Oxygen Level

Irrigated Marsh Ponds

Initially the two irrigated marsh ponds occupied about four acres each. However, water seepage and evaporation losses were so great that it was necessary to reduce the ponds to about 1.5 acres each, and the first year of operation was lost. When acquired, the area had a pure stand of onley bulrush which has almost no food value. Except for the summer of 1976, flooding of the ponds was from October to May and according to the recommended management to practice for the Suisun Marsh. During the summer of 1976, the watergrass pond was flooded to assure maturity of the watergrass that was planted late in April. Water supply to the watergrass pond was the combined outflow from the algae ponds. The algae ponds were drained down to about one half normal depth in October for water supply to flood the watergrass pond then gradually refilled during November, December and January. The supply to the bulrush pond was a combination of wastewater from the detention pond and tile drainage from the pasture. From September 1975 to the spring of 1976, all the water supply was used on the watergrass pond in an attempt to flood-kill the stand of onley bulrush, with fair results.

Nitrogen. Except for the winter of 1975 in the watergrass pond and in the bullrush pond in the fall of 1976, both ammonia and nitrate plus nitrite were less than 2 milligrams per liter and totaled less than 1 milligram per liter much of the time, with maximum concentration of nitrate of about 5 mg/L (figure 12).

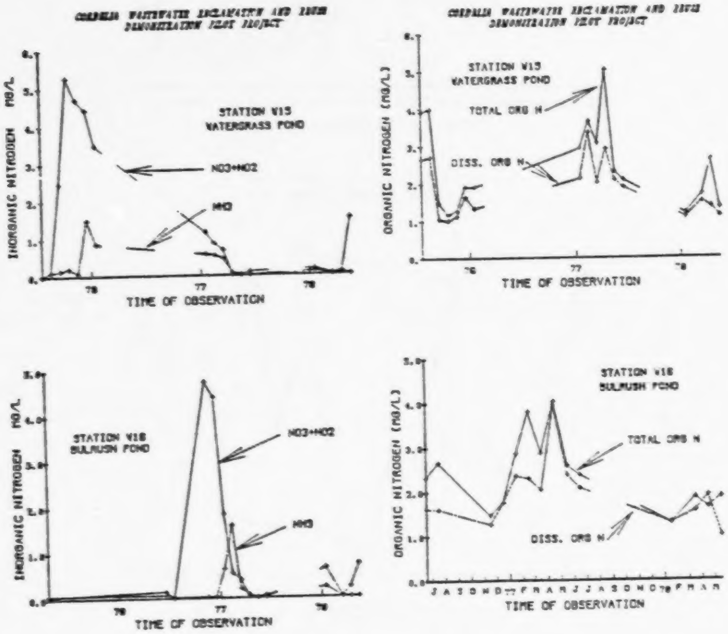


Figure 12. Marsh Pond Nitrogen

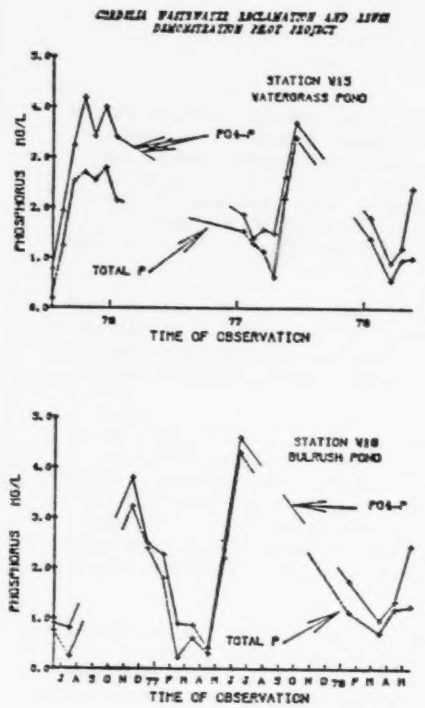


Figure 13. Marsh Pond Phosphorus

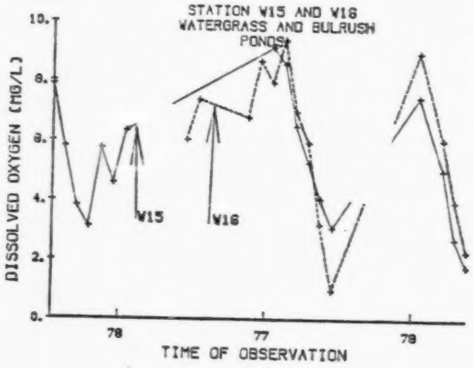


Figure 14. Marsh Pond Dissolved Oxygen

Total organic nitrogen averaged less than 3 milligrams per liter, with the concentration of the dissolved fraction usually near 2 milligrams per liter, about the same as in algae pond, detention reservoir outflow and the pasture drainage. Most of the particulate organic nitrogen in the algae pond and detention reservoir outflow was removed in flow through the grass ponds.

Phosphorus. Ortho and total phosphorus in grass pond outflow varied from less than 1 to more than 4 milligrams per liter with only a slight difference between ortho and total phosphorus (figure 13). Phosphorus removal averaged about 25 percent, and the slight difference between ortho and total phosphorus indicated the degradation of organic and poly phosphorus that was evident in the pasture drainage and algae ponds continued in the grass ponds.

Oxygen. Dissolved oxygen in the watergrass and bulrush ponds was above 5 mg/L most of the time (figure 14). Dissolved oxygen decreased late in the spring and was lowest in May when the ponds were being drained. Low dissolved oxygen during the late spring and when draining is common in duck club ponds, due to increased decomposition of vegetative detritus that accumulated during the winter.

SUMMARY

Although the limited supply of wastewater, water control problems in the grass ponds and limited depth of the algae ponds provided less than optimum results, the overall study results were encouraging, and in the fall of 1977 the Bureau of Reclamation began a study of the use of wastewater from the new Fairfield Subregional Waste Treatment Facility by three duck clubs with pond areas ranging from 100 to 350 acres (25 to 140 hectares). Another club using water from an adjacent slough is being used as a control unit.

It was found that the algae ponds could be used much of the year to provide water storage and treatment of wastewater for supply to the irrigated marsh ponds. However, use from June through August was not feasible, with excessive growth of filamentous algae and rooted pondweeds causing low dissolved oxygen levels.

There were no environmental problems encountered in the irrigated marsh ponds. Actually, by the end of the study desirable waterfowl forage plants had largely replaced the existing stand of onley bulrush. Draining and drying the grass ponds during the summer, June 1 to October 1, was effective in limiting the growth of cattails and tules. Nitrogen removal was good, and within the limitations of water control generally produced outflow with less than 3 milligrams per liter inorganic nitrogen.

Wastewater was a satisfactory source of irrigation water for the pasture but the tile drainage system was essential in preventing a buildup of water and salts in the root zone. Although considerable salt remained in the soil, a great amount was removed in the drainage and lowered soil salinity sufficiently to grow oats.

STATE-OF-THE-ART OF WATER RECYCLING IN FISH CULTURE FACILITIES

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The fisheries of the world provide a significant proportion of the necessary protein in the diet of the population of this world. Among the more affluent societies, sports fishing may assume a status equivalent to the commercial fishery. In either case, whether for food or for sport, the supply of fish available to the fisherman cannot be allowed to be depleted. Yet overfishing, pollution, dams and water intakes all take their toll of the fishery to reduce the supply. Husbandry of this natural resource is as necessary as that for beef, wheat or rice. To this end the field of aquaculture is gaining recognition as a vital part of today's life cycle. Mullet, carp, bass and catfish are some of the warm water species being reared; muskie, walleye and pike are some of the cool water species being cultured; and the salmonids, salmon and trout, are the principal cold water species being artificially propagated. This paper deals primarily with the latter.

Economical propagation of the salmonids requires intensive rearing, by which is meant rearing at high densities in terms of both habitat volume and water flow. But to survive, these salmonids need high quality water: high in dissolved oxygen, low in pollutional characteristics, free of toxic substances. They are a delicate species. They thrive on large flows of pristine waters. However, the existence of such is being depleted more rapidly than the fishery. Lacking plentiful supplies of pure, slightly hard (pH 7.5), 60 degrees F (15.5 degrees C) water, small supplies of water of any quality may be treated and retreated in a recycling program to provide the life-sustaining needs of these tender organisms.

To establish a scale for the subject of this paper, the usual fish hatchery water demands range in the order of 10 to 50 cfs (0.28-1.41 m^3/s). A project currently in design will utilize a 200 cfs (5.70 m^3/s) spring supply. Such flows are comparable to municipal water systems for major cities.

DEFINITIONS

Three types of water supplies may be and are utilized in the rearing of salmonids: flow-through, reuse and recycle. Flow-through is defined as a single use of "cool, clear water". Abundant supplies of such are becoming much less readily available. It might be compared to an outdoor, mountain-air human environment.

Reuse is defined as repeated use of the same water with successive reductions in water quality. It might be compared to an office complex with windows at each end of the complex.

Recycle is defined as repeated use of the same water with water quality improvement between each use. It might be compared to an office complex with complete air-conditioning.

Except, perhaps for Alaska, where we are designing a flow-through system for the Tamgas Creek Hatchery on Annette Island, and except for Idaho and New Zealand where the author's firm has proposed reuse systems for the Clearwater and Bubbling Springs Hatcheries, limited water supplies are demanding recycle systems to meet production objectives. An example of the demand was emphasized a year ago during the western drought. Several years before, the author's firm had designed two hatcheries for the State of Utah, one a complete recycle system, and one primarily a reuse system. The Utah Division of Wildlife Resources advised that because of low water flows throughout the state, the one complete recycle system supplied nearly the total fisheries production for their entire state.

THE RECYCLE SYSTEM

The simplified recycle system is depicted in Figure 1. The more comprehensive, complex system, complete with equations, is described in the Appendix. A small amount of fresh water is added to, and simultaneously a small amount of used water is wasted from a relatively large body of water that is sequentially passed through a rearing unit and a treatment unit. Theoretically, a completely closed cycle unit could be constructed with make-up limited to evaporation, but such would require an especially sophisticated, and expensive treatment unit. The practical minimum make-up seems to be about 5 percent, with 10 percent being a more common value.

Within the rearing unit, the fish consume oxygen and excrete urea, CO_2 and ammonia. For salmonids minimum dissolved oxygen levels are 5 mg/l, maximum ammonia levels are 0.5 mg/l, and salmonids have practically no tolerance for nitrites, but can withstand nitrates to concentrations of 400 mg/l. Disease and infections must be minimized, if not eliminated, and turbidity must be lowered to a point where feed may be accepted by the fish. The treatment unit(s) must accomplish the foregoing objectives.

TREATMENT

Depending upon the quality of make-up water, pre-treatment may involve straining, micro-straining, or filtering; disinfection; pH control; aeration/de-aeration; and temperature adjustment. In-process treatment may involve the same corrective measures plus ammonia removal.

Physical Separation

Within the recycle system physical separation in the form of sedimentation and straining is necessary to remove the fish metabolites from the system. But the principal role of physical separation within a fish culture unit relates to pre-treatment of surface water supplies which may contain anything from logs to leaves to sand to silt. Bar racks, or "grizzlys" at the intake remove the gross debris such as logs. Sloping screens - perforated plates at a downstream slope of about 1:10 - are effective at removal of leaves, twigs and needles and are essentially self-cleaning. Rotary screens are also frequently used for this service. Sedimentation is usually the most effective means of removal of sand, although centrifugal separators have proven effective, especially on pumped supplies. It must be remembered that hatchery raceways with velocities less than one-tenth foot per second (0.03 m/sec.) are excellent sedimentation chambers. Whatever is not removed in pretreatment, will very likely settle out in the rearing unit.

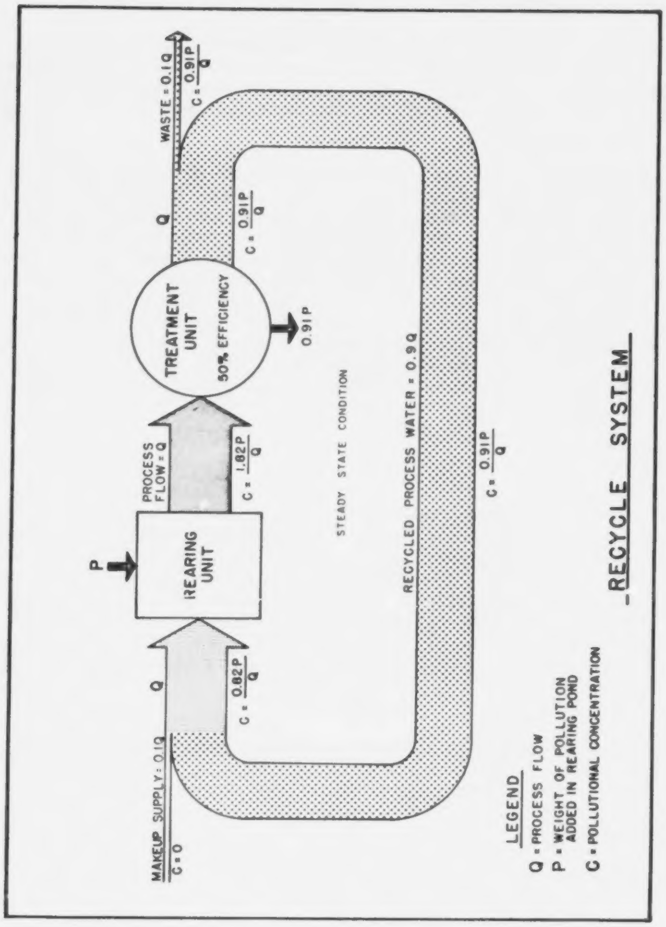

MAKEUP SUPPLY = 0.1Q
C = 0
Q
C = 0.82P/Q
P
REARING UNIT
PROCESS FLOW = Q
C = 1.82P/Q
TREATMENT UNIT
50% EFFICIENCY
0.91P
Q
C = 0.91P/Q
WASTE = 0.1Q
C = 0.91P/Q
STEADY STATE CONDITION
RECYCLED PROCESS WATER = 0.9Q
C = 0.91P/Q
LEGEND
Q = PROCESS FLOW
P = WEIGHT OF POLLUTION ADDED IN REARING POND
C = POLLUTIONAL CONCENTRATION
RECYCLE SYSTEM

FIGURE 1

Sand or mixed-media filtration has heretofore been the accepted practice for removing the finer silts and disease organisms. But the experience with such units has not been altogether satisfactory. It is suspected that "piping" or "blow-throughs" in filters may be responsible for the introduction of disease organisms, particularly, into apparently well-protected systems. For this reason the trend seems to be away from filters and toward microstraining which can readily remove down to twenty microns without the possibility of unobserved "blow-throughs". Capital and operating costs favor microstraining as well.

If necessary, colloidal material could be removed by flocculation, sedimentation and filtration as in standard municipal water treatment processes, but a water supply requiring such extensive treatment for a fisheries application has not yet (fortunately) been encountered by the author.

The rearing unit, too, can significantly aid in physical separation of metabolites generated within the rearing system. Burrows (1) has shown by extensive hydraulic testing that if the metabolites can be moved by the currents within the rearing system to the waste discharge point, separation of wastes is both more convenient and effective. Geometry of the rearing units, and means of water introduction to the rearing units thus assumes significance. For circular tanks or ponds, circumferential periferal injection of water under pressure, and discharge screens square in plan jointly accomplish the desired objective. For larger rearing units, the rectangular circulating, or "Burrows" ponds, when constructed to conform to the empirically derived hydraulic criteria, are especially effective.

pH Control

Salmonid rearing is sensitive to the pH of the water supply. Soft waters lack the necessary minerals to insure hardy growth of the young fish and can dissolve toxic metals from pipes and containers. Hard waters encourage the generation of un-ionized ammonia in rearing waters, which can be especially deleterious to the fish. Natural water supplies are sought that demonstrate a slightly hard (pH = 7.5 ±) condition. Where natural waters are not found to be at an optimum hardness lime may be added to increase the pH, or dilute acid may be added to decrease the pH. However, major pH adjustments are not economically feasible.

Iron

Optimum concentrations of iron are below 0.3 mg/l. Above 0.7 mg/l iron concentrations can cause significant gill disease. Aeration and filtration, possibly (but carefully) with the assistance of potassium permangenate, can be utilized to reduce excessive iron concentrations to acceptable limits.

Aeration/De-aeration

One of the beauties of nature is that both super-saturated water and sub-saturated water seek to achieve the neutral saturated condition given the opportunity. The opportunity usually involves agitation of some form. Aeration/de-aeration has been proven by Burrows (2) to be effective when aspiration is utilized. For waters low in oxygen, 90 percent or more of saturation can readily be achieved by aspiration. Aeration by aspiration at the Glenwood Hatchery in Utah is pictured in Figure 4. For super-saturated waters, a saturated condition can also be achieved by aspiration. At the Maple Springs Hatchery in Utah, the water supply was found to be 160 percent of saturation. "Gas-bubble disease" had been prevalent. Two-step de-aeration by aspiration reduced saturation to very satisfactory limits. However, the requirement for de-aeration (or aeration) by aspiration requires a pressure of 18 psi (1.26 kgf/cm^2) in the supply header. This is energy expensive. A search for alternative aeration/de-aeration methods has not proven fruitful. In practice, floating aerators seem to be effective, but calculations indicate tremendous horsepower requirements as saturation is approached. Frankly, most of the work in this area to date has been related to low saturation sewage lagoons. It seems that floating aerators are more effective than calculations indicate, but as yet this has not been substantiated. There is a substantial economic incentive for investigations in this area.

Temperature Adjustment

Rarely does the temperature of natural waters satisfy the fish culturist. He wants one temperature for his eggs, another for the fry, and perhaps a third temperature (or several temperatures) for his fingerlings. Usually this requires boilers or chillers. Solar energy is being investigated as an alternative to the consumption of fossil fuels or electricity. Solar ponds appear particularly advantageous, although such have not yet actually been used in fish culture to the author's knowledge. On the other hand, heat pumps are and continue to be used to reduce the gross energy demand.

Disinfection

In aquaculture facilities disinfection takes two forms: disinfecting the fish and disinfecting the water supply. The former is performed on a periodic basis by adding chemicals such as formalin, malachite green or Diquat to the rearing unit to provide short duration baths. These biodegradeable chemicals are discharged from the rearing system to the process waste water treatment facility.

Disinfecting the water supply is more difficult because the fish are very sensitive to the usual disinfection agents: chlorine and ozone. Salmonids are sensitive to total chlorine residuals of 0.102 mg/l and to concentrations of ozone as low as 0.008 mg/l.

Dechlorination is feasible and at least one major hatchery, that of Weyerhaeuser's Oregon Aqua Foods Division in Springfield, Oregon, utilizes chlorination and subsequent dechlorination by the sodium thiosulfate process to treat a river water supply. However, very close monitoring and control of the process is necessary to insure avoidance of carryover of chloramines.

Ozonation, too, is feasible since ozone is very unstable in solution. With a half-life of 6.9 minutes air stripping or simple retention can theoretically make ozone treated water safe for fish. However, in any such system short-circuits are possible, and since toxicity is less than measureable limits by several orders of magnitude, a "safe" de-ozonation system would tend to require design over-kill with attendant high costs. The author knows of no major production hatchery utilizing ozone for disinfection.

For reasons cited above ultra-violet disinfection is the usual accepted method in fish culture facilities. Ultra-violet treatment must be used in conjunction with filtration or microstraining becuase its effectiveness is dependent upon the size of the organism. Furthermore there is no simple way of testing the water to monitor the effectiveness of ultraviolet disinfection. Only the lamp intensity and water flow rate can be monitored.

Most operational fish culture facilities use pressurized U-V systems with attendant high operating and capital costs. Gravity U-V systems have recently come on the market, however, to substantially reduce such costs. A 33.3 cfs (0.945 m^3/s) gravity U-V unit has been operating at the Greenlake Hatchery in Maine for several years.

Ammonia Removal

The heart of the fish culture recycle system is the component designed to remove ammonia because here all of the metabolic waste products of the fish are, or should be eliminated, or reduced to acceptable limits. This component should incorporate physical separation and either biological or chemical reduction.

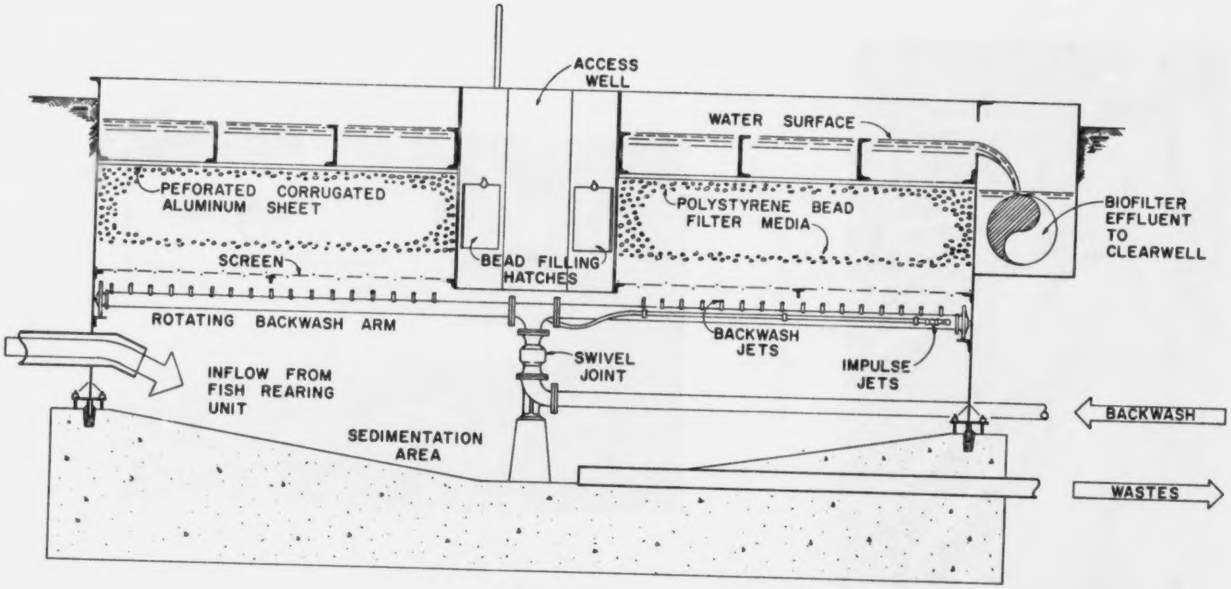
The first, and to date the only systems untilized in full-scale production hatcheries have been biological filters. Speece (3) described the theory of biological filters.

Down-flow rock and oyster shell filters were first used. These were much like conventional rapid sand filters but with larger media. The principal problem that developed with these filters was the effectiveness of the backwashing system, even when the backwash water was air-assisted. Clogging due to metabolic solids occurred, and in some systems the filters were preceded with separate sedimentation chambers.

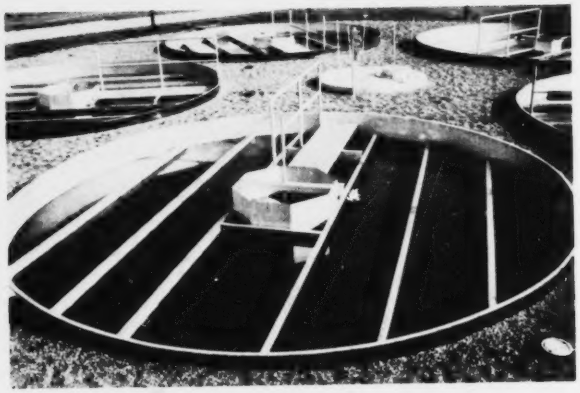
To reduce the foregoing backwash problem the Corps of Engineers first used plastic rings as media in an upflow system at the Dworshak Hatchery in western Idaho. This was recently converted to a media composed of of short, about 3/8-inch (0.015m) long sections of polyethylene cylinders about 1/4-inch (0.010m) in diameter, which have nearly neutral buoyancy. Allaire (4) reports that these efforts are effective.

The author's firm has favored the upflow system of biological filter utilizing polystyrene media as depicted in Figure 2. The biofilters at the Mixsawbah State Fish Hatchery in Indiana are pictured in Figure 3. The very low density, approximately one pound per cubic foot (0.0129 kg/m^3), of this media requires a substantial hold-down structural restraint capability, but it is easy to backwash. Further, the compartment below the media provides sedimentation and the media, itself, provides straining. The media is effective in developing a biological growth to reduce ammonia, first to nitrites and, immediately to nitrates.

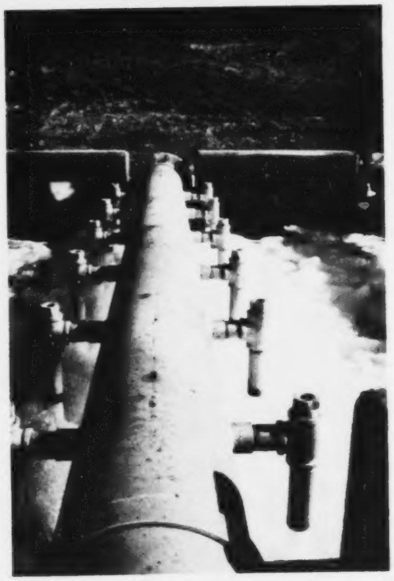
In 1974 Williams (5) reported on research with chemical ammonia removal utilizing clinoptilolite as the ion-exchange medium. Private communications indicate that the Anaconda Copper Company and Becker Industries are ready to put such a unit on the market for full-scale production. Regeneration is by a brine solution. Costs and procedures have not been made fully public. Filtration is involved which provides the necessary physical separation of metabolites.



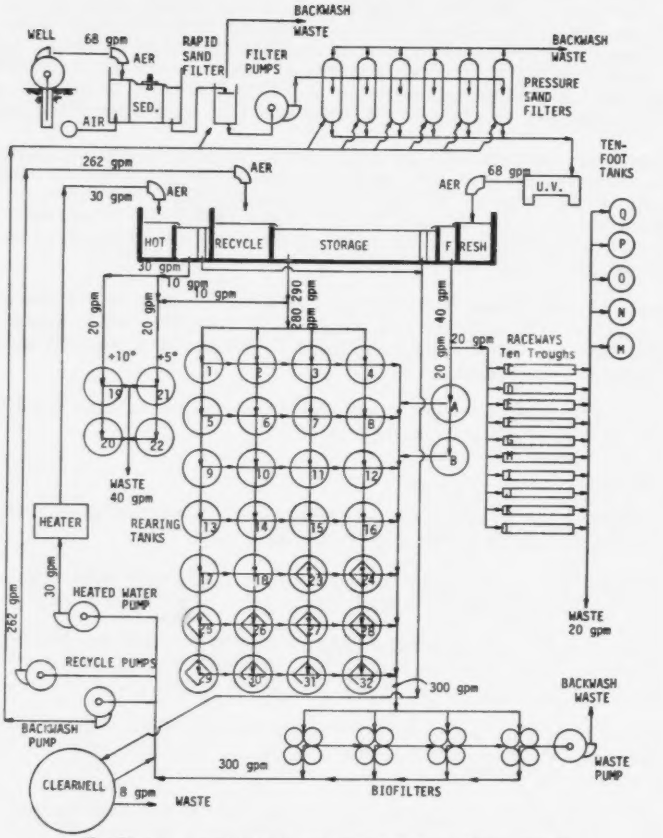
BIOFILTER
FIGURE 2



MIXSAWBAH BIOFILTERS
FIGURE 3



GLENWOOD AERATION
FIGURE 4



Flow Diagram - Consolidated Edison Research Hatchery, Gorham, Illinois

FIGURE 5

FLOW DIAGRAM

The flow diagram for the Gorham Research Facility is depicted in Figure 5. While this was a small research hatchery, and involved low flows, it does demonstrate the full gamut of recycle aspects including extensive pre-treatment, heating a portion of the process water, and providing a parallel flow-through system to a portion of the rearing units.

COSTS

Based upon a facility currently being designed to recycle 7,200 gpm (455 liter/sec.) a complete recycle unit is now costing $65 per gpm ($1030 per liter/sec.) to construct. Included in these costs is bio-filtration, aeration by aspiration with elevated aeration tank, a clear-well, pumps, piping electrical service, standby electrical generation, engineering and project management. Electrical service to operate such a facility amounts to sixteen watts per gpm (254 watts per liter/sec.).

Assuming a ten percent make-up water supply for the foregoing recycle system, comparable installed costs for some of the pre-treatment units would be in the order of $80 per gpm of supply ($1270 per liter/sec.) for microstraining and $40 per gpm of supply ($635 per liter/sec.) for ultra-violet disinfection. Per unit of recycle flow costs would be ten percent of the foregoing.

It should be emphasized that capital costs for recycle facilities are significantly influenced by flow rates. The foregoing costs would increase rapidly as flow rates are reduced and would decrease slowly as flow rates are increased.

The cost of a recycle system for a fish hatchery constitutes about 25 percent of the total cost of the hatchery.

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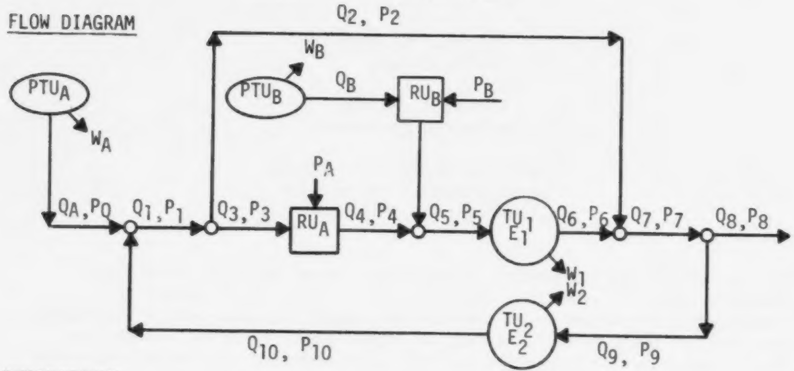
5. Williams, W. G., Evaluation of Clinoptilolite for Ammonia Removal, Proc. 25th Northwest Fish Culture Conference, Seattle, WA. (1974).

APPENDIX

GENERAL RECYCLE EQUATIONS

FLOW DIAGRAM



DEFINITIONS

RU	Rearing unit of hatchery
TU	Treatment unit
PTU	Pre-treatment unit
Q	Water flow rate thru system segment
Q_7	Total Q thru combined system
A	% of Q_7 added to system ahead of RUA
B	% of Q_7 added to system ahead of RUB
R	% of Q_7 recycled
X	% of (A + R) Q_7 flowing thru RUA
P	Weight of pollutant in system segment
P_A, P_B	Weight of pollutant added at RUA, RUB
E	% efficiency of TU (varies with type of P)
W	Weight of pollutant removed in TU
C	Concentration of pollutant = P/Q
K	Ratio of $P_7/(P_A + P_B) = \dfrac{(1 - E_1)}{1 - R\ (1 - E_2)\ (1 - E_1X)}$

EQUATIONS

$Q_A = AQ_7$

$Q_1 = (A + R)\ Q_7$

$Q_2 = (1 - X)\ (A + R)\ Q_7$

$Q_3 = X\ (A + R)\ Q_7$

$Q_4 = Q_3$

$Q_5 = [B + X\ (A + R)]\ Q_7$

$Q_6 = Q_5$

$Q_7 = Q_2 + Q_5$

$Q_8 = (1 - R)\ Q_7$

$Q_9 = RQ_7$

$Q_{10} = Q_9$

$P_0 = 0$

$P_1 = KR\ (1 - E_2)\ (P_A + P_B)$

$P_2 = KR\ (1 - X)\ (1 - E_2)\ (P_A + P_B)$

$P_3 = KRX\ (1 - E_2)\ (P_A + P_B)$

$P_4 = P_A + KRX\ (1 - E_2)\ (P_A + P_B)$

$P_5 = (P_A + P_B)\ [1 + KRX\ (1 - E_2)]$

$P_6 = (1 - E_1)\ (P_A + P_B)\ [1 + KRX\ (1 - E_2)]$

$P_7 = K\ (P_A + P_B)$

$P_8 = K\ (1 - R)\ (P_A + P_B)$

$P_9 = KR\ (P_A + P_B)$

$P_{10} = P_1$

$W_1 = E_1\ (P_A + P_B)\ [1 + KRX\ (1 - E_2)]$

$W_2 = E_2KR\ (P_A + P_B)$

A COMBINATION OF AQUATIC AND TERRESTRIAL ECOSYSTEMS FOR MAXIMAL REUSE OF DOMESTIC WASTEWATER

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The continuing public demand for more stringent wastewater effluent standards and the rapidly escalating energy costs of meeting these standards with conventional, mechanical facilities has led to increased interest in using natural ecological assemblages to treat wastewater. The potential of such systems to recycle wastewater nutrients with solar energy to yield products of value rather than residual sludges with their additional disposal costs is of particular appeal. Moreover, it is tempting to picture a natural, solar powered wastewater recycling system which produces large amounts of food and fiber, serves as a recreation site, and recharges groundwater and surface water resources with high quality water. The potential for meeting these various desires is tied directly to establishment of sufficient understanding of the ecological mechanisms underlying wastewater processing by natural ecosystems so that design criteria for such systems can be based upon ecological reality.

THE WATER QUALITY MANAGEMENT FACILITY

The Michigan State University Water Quality Management Facility (WQMF) was constructed as a field-scale research facility to evaluate limits to wastewater processing imposed by ecological mechanisms in both aquatic and terrestrial systems. Secondary wastewater effluent is pumped 7.25 km from the East Lansing, Michigan, activated sludge wastewater treatment plant to the 200 ha WQMF on the southern margin of the Michigan State University campus. There the wastewater flows by gravity through a series of four ponds to a pump-house from which it is applied as spray irrigation to the 130 ha terrestrial site.

The ponds range from 3.23 to 4.98 ha with a total surface area of sixteen ha. Maximum pond depth is 2.4 m at the outlet, and mean operating depth of each pond is 1.8 m. The entire pond bottom is within the photic zone to encourage growth of aquatic macrophytes. During construction, the ponds were sealed with native clay yielding a low permeability of 0.18 cm/day.

The outlet structure of each pond allows withdrawal of water from the top, bottom, and mid-depth levels. The incoming secondary effluent can be sprayed directly on the terrestrial site or can be mixed with water from each of three depths from each of the four ponds at the pump-house to allow a wide variety of water quality for terrestrial application.

The terrestrial site consists of a 58 ha irrigation area surrounded by a 72 ha aerosol buffer zone. The soils on this site are heterogeneous both horizontally and vertically but are dominated by loams, loamy sands, or sandy loams of the mixed mesic family of Typic Hapludalfs. The hydraulic limit for this area averages five cm/wk but varies from zero to twenty cm/wk. The terrestrial site includes abandoned farm lands with typical old-field vegetation, a sugar maple-beech forest, a tree plantation, and an area containing several important agronomic crops.

While conceptually designed to accept 7,570 m^3/day (2 MGD) of secondary wastewater, the WQMF has been operated at rates ranging from 1,892 m^3/day (0.5 MGD) to almost 3,785 m^3/day (1 MGD).

THE PONDS

After the ponds were filled with wastewater, the three lower ponds were planted with a wide variety of aquatic plants characteristic of the region. Fathead minnows and largemouth bass were planted into the fourth pond to allow evaluation of the potential of such systems for fish production.

The secondary wastewater pumped from the East Lansing, Michigan, activated sludge system to the WQMF contains about twenty mg N/ℓ and five mg P/ℓ with an alkalinity of about three meq/ℓ. Impoundment of this enriched water in the ponds stimulates photosynthetic carbon uptake by both algae and aquatic macrophytes at a rate greater than carbon dioxide can be supplied from the air. The secondary effluent contains little BOD, and thus little carbon dioxide is supplied by bacterial respiration of wastewater borne organics.

The demand for a photosynthetic carbon dioxide source, stimulated by the abundant nitrogen and phosphorus, is met by dissociation of the carbonate-bicarbonate alkalinity system as shown in equations 1, 2, and 3.

$$HCO_3^- + H^+ \rightleftharpoons CO_2 + HOH \qquad (1)$$

$$HCO_3^- \rightleftharpoons CO_3^= + H^+ \qquad (2)$$

$$2\ HCO_3^- \rightleftharpoons CO_2 + CO_3^= + HOH \qquad (3)$$

Incorporation of carbon dioxide from the alkalinity into the aquatic plants at a rate greater than the atmospheric recarbonation rate results in increased pH, decreased free carbon dioxide concentrations,[1] precipitation of a variety of metal oxy-hyroxides and carbonates,[2] and a loss of ammonia to the atmosphere as shown in the equilibrium in equation 4 for which the pK is about 9.2 at summer temperatures.[3]

$$NH_4^+ \rightleftharpoons NH_{3(g)} + H^+ \qquad (4)$$

Since time is required for photosynthetic extraction of carbon dioxide from the alkalinity, the pH in ponds charged with wastewater increases as a direct function of detention time.[2] Continued photosynthetic carbon dioxide fixation from the alkalinity results in continually increasing pH until the carbon dioxide concentration in the water is reduced to the threshold level required by the most competitive aquatic plant.[4] At that point, continued detention of the wastewater allows maintenance of the pH at a high level, but the pH of the wastewater cannot be increased further.

Within the WQMF, pH routinely exceeds ten in the three downstream ponds during the summer months. During the summer of 1976, with a 1,892 m^3/day loading through the ponds, the macrophyte, Elodea canadensis, maintained the pH well above ten within the second pond for several weeks with no attempt to manage vegetative growth.

The significant carbon dioxide extraction by algae and macrophytes which elevates the pH is accompanied by a variety of changes in other equilibria and causes many alterations in other water quality parameters which determine removal and recycle of nitrogen and phosphorus and the type of biotic community the ponds can support.

Phosphorus Removal by the Ponds

Phosphorus removal from wastewater in ponds is limited to direct sorbtion of phosphorus by bottom sediments, settling of metal-phosphate precipitates, and by removal of phosphorus-rich biological tissues formed in the ponds. Sediment sorbtion of phosphorus is finite and declines with time, and metal-phosphate precipitates formed during periods of high pond pH are dissolved within the WQMF ponds during periods of low pond pH associated with the occasional severe respiratory events. Harvest of aquatic vegetation offers the only other realistic means of removing phosphorus from wastewater ponds.

During 1976 when the WQMF was loaded with secondary effluent at the rate of 1,892 m^3/day for flow through the four ponds and with additional water to meet the irrigation demand, 18,928 kg dry weight of filamentous algae and macrophytes were harvested from the first, second and fourth ponds. The total amount of phosphorus removed by this plant harvest was only 132 kg of elemental phosphorus. Population estimates of the aquatic plants just before harvest indicated that maximum harvest efficiency was about 50 percent of the standing crop. But, even if all plants which grew in all four ponds had been harvested, the total phosphorus removed would have been about ten percent of the annual load at a loading rate of 1,892 m^3/day of secondary wastewater containing five mg P/ℓ.

The limited saturation potential of the bottom sediments, the transitory nature of phosphate removal by metal precipitates and the inability of aquatic plants to capture sufficient amounts of phosphorus led to establishment of phosphorus concentrations in the fourth pond exceeding the one mg P/ℓ effluent standard which in turn led to cessation of throughput loading of wastewater to the ponds.

When first put into use, ponds will show excellent phosphorus removal from wastewater; but once the available phosphorus sorbtion sites are filled, there is no mechanism in a pond system which allows continued phosphorus removal at anything approaching the rate required to meet effluent standards.

Nitrogen Removal by Ponds

Nitrogen contained in the wastewater is incorporated by algae and macrophytes within the ponds. Respiratory use of the resulting plant tissue, particularly by the bacteria, markedly accelerates the biogeochemical cycle of nitrogen increasing the frequency at which each atom of nitrogen will appear as the ammonium ion. At the high pH levels maintained in the ponds, the ammonium ion is rapidly converted to ammonia gas as was shown in equation 4 and is lost to the air.

During the occasional severe respiratory events associated with rapid bacterial use of decaying plant masses, denitrification undoubtedly is of import in stripping nitrogen from wastewater ponds. Within the WQMF such respiratory events occur at times, but the high pH and oxygen concentrations well above atmospheric saturation maintained most of the time throughout these ponds would tend to minimize denitrification.

Only a small amount of the nitrogen lost during the summer of 1976 can be accounted for by plant harvesting. In fact, even with the large mass of plants removed from the ponds, only nine percent of the nitrogen removed from the wastewater during that period can be accounted for in harvested aquatic plants.

The dynamic nature of the ponds and the loss of nitrogen directly to the atmosphere as ammonia and as nitrogen gas through denitrification yielded extremely efficient nitrogen removal from the WQMF ponds during 1976. The total nitrogen concentration decreased as a function of detention time as shown in equation 5.

$$N_t = N_o^{-.03t} \tag{5}$$

Where: N_t = total nitrogen concentration (mg N/ℓ) at time t,

N_o = initial total nitrogen concentration (mg N/ℓ), and

t = time in days.

Thus, total nitrogen was reduced from the incoming values of fifteen to twenty mg N/ℓ to levels of about 0.5 mg N/ℓ. Inorganic nitrogen concentrations after a detention time of 120 days were often as low as 0.01 mg N/ℓ.

The rate of nitrogen removal within each of the WQMF ponds was related in a linear fashion to the concentration of inorganic nitrogen entering each pond as shown in equation 6.

$$N_R = -0.017 + 0.038\ N_c \tag{6}$$

Where: N_R = rate of nitrogen removal (g N/m^2 pond surface/day), and

N_c = influent inorganic nitrogen concentration (mg N/ℓ).

All data available to date indicate that the significant nitrogen removal from wastewater in ponds is a direct function of the time-related changes in water chemistry triggered by photosynthetic activity of algae and macrophytes in these carbon-limited aquatic systems.

Fish Production Potential

During the period when wastewater was put through the four ponds, the largemouth bass in the fourth pond took advantage of the high production of insects and small fish and grew at rates equal to those in productive lakes in Florida and Louisiana.[5] To maintain the fish in this pond it was necessary to harvest the dominating large crop of macrophytes to prevent oxygen depletion associated with the bacterial degradation of this plant tissue.

After wastewater throughput was stopped because of the inability of the ponds to remove phosphorus, the water added to the fourth pond did not contain sufficient nitrogen to allow macrophyte dominance. Vegetative production was largely periphytic algae on the pond bottom which could not be harvested. Bacterial use of this material in August of 1978 caused marked oxygen depletion and a significant, but not total, fish kill.

The ability of such pond systems to strip nitrogen from the wastewater causes nitrogen limitation of aquatic plants which can lead to establishment of large populations of nitrogen fixing blue-green algae as happened in the third WQMF pond during the past two summers. Inability to harvest these algae results in almost total oxygen depletion during later portions of the year. Thus, the long-term production of fish in these ponds appears to be limited by a system imposed shortage of nitrogen which limits plant production in the downstream ponds to forms which cannot be harvested. Fish kills result from the exertion of the BOD contained in the plants.

LAND IRRIGATION

The addition of wastewater nitrogen to the WQMF terrestrial site would be maximized by direct irrigation of the incoming secondary effluent. However, the secondary effluent enters the facility continuously and irrigation of the terrestrial site is an intermittant operation. As such, the rate of withdrawal during periods of irrigation exceeds the rate of the input from East Lansing and water is back-siphoned from the first pond to meet the irrigation demand. Even this temporary impoundment in the first pond results in significant nitrogen loss. An example of this nitrogen loss is seen in data from May of 1977 when 844 kg of nitrogen were pumped from East Lansing to the WQMF. Of this amount, 397 kg of nitrogen were applied to the terrestrial site and 379 kg of nitrogen were lost to the air from just the first pond. Thus, the nitrogen concentration of the water applied to the various portions of the terrestrial site varies as a function of the number of sites being irrigated at one time but is usually in the ten to fifteen mg inorganic N/ℓ range. All water applied to the terrestrial site is chlorinated prior to spray irrigation. Wastewater has been applied to old abandoned farm fields dominated by goldenrod and quackgrass, to older suger maple-beech forests and to several varieties of forage crops during the summer and to old-fields during the winter. The major findings of this research are summarized below.

Forests

Wastewater was spray irrigated on a sugar maple-beech forest at rates of five and ten cm/wk while a control plot was not irrigated and received only the nitrogen and phosphorus contained in natural precipitation.[6,7] Total nitrogen and phosphorus input to each irrigated forest plot included natural precipitation addition plus that contained in the wastewater. Water infiltrating past the root zone was sampled with tube-type porous cup vacuum lysimeters placed at a depth of 150 cm for analysis of nitrogen and phosphorus concentrations. The discharge volume and nitrogen and phosphorus concentrations of surface runoff also were monitored. Wastewater available for groundwater recharge was calculated with the water budget method of Thornthwaite and Mather[8] and was used with the above data to construct the mass balances for nitrogen and phosphorus given in Tables 1 and 2.

At an irrigation rate of five cm/wk all water infiltrated and the porous soils were very efficient at phosphorus removal (Table 2), but most of the nitrogen applied leached through the root zone on its way to the groundwater (Table 1). Most of the time concentrations of inorganic nitrogen at the 150 cm depth were similar to concentrations in the applied wastewater.[6]

With an irrigation rate of ten cm/wk the soil was water-logged to the point where trees died in the lower portion of the forest where the water pooled.[7] This water-logging reduced contact of wastewater with the soil resulting in significant amounts of runoff of both nitrogen and phosphorus as can be seen in Tables 1 and 2. In addition, the 71 percent nitrogen retention noted in Table 1 for this site includes all nitrogen lost through denitrification from the water-logged soil which accounts for almost all of this apparent retention.[7]

Old-Fields

Wastewater was spray irrigated on old-fields at rates of five and ten cm/wk and, as in the forest study, a non-irrigated control also was monitored.[6,9] Data were collected for calculation of nitrogen and phosphorus mass balances for these old-field plots in the same manner used for the forest except that lysimeters were placed at a 120 cm depth instead of the 150 cm depth used in the forest studies. To evaluate the role of plant harvest in the management of nutrients applied to wastewater irrigated fields, control and five and ten cm/wk irrigated plots were subjected to a plant harvest regime of no harvest, a June only harvest, and a harvest in both June and September. As in the forest study, the control plots received only the nitrogen and phosphorus contained in natural precipitation while the irrigated plots received the sum of the nitrogen and phosphorus contained in both the natural precipitation and the applied wastewater. The mass balances of nitrogen and phosphorus resulting from these various irrigation and harvest treatments are presented in Tables 1 and 2.

Regardless of treatment, the old-fields exhibited extremely efficient phosphorus removal while nitrogen removal was to some extent a function of treatment (Tables 1 and 2). Harvest of plants increased nitrogen removal efficiency primarily because such harvests encouraged continued growth of the old-field vegetation. In the unharvested plots, plant growth slowed and biomass began to decrease by mid-August with the concomitant increase in the nitrate concentration below the plant root zone from one to three mg NO_3-N/ℓ to concentrations approaching ten mg NO_3-N/ℓ by late October. Prior to mid-August there was little difference in nitrogen and phosphorus removal regardless of treatment.

In addition to extending the nutrient retention capacity of the site through removal of nitrogen and phosphorus, harvest of plants also encouraged continued growth of the old-field vegetation yielding an extension of the effective renovation period from mid-August to late October. In general, the old-fields of the WQMF are extremely effective at phosphorus removal and can be managed to yield significant nitrogen and phosphorus recycle as harvested vegetative biomass while maintaining nitrate concentrations in the water recharged to the groundwater well below the suggested limit of ten mg NO_3-N/ℓ during those periods of the year when there is active vegetative growth.

Crops

The ability of agronomic crops to remove nitrogen and phosphorus from wastewater was evaluated on the WQMF by irrigating eight varieties of perennial grasses, eight varieties of legumes, and four varieties of annuals (corn, sorghum-sudan hybrids) at rates of 2.5, 5.0, and 7.5 cm/wk.[10] In addition, no vegetation plots, maintained by application of herbicides, were irrigated at rates of 5.0 and 7.5 cm/wk. The crops were harvested in a typical agronomic fashion. A small amount of fertilizer was added to all cropped plots at a level of 22.4, 9.7 and 111.5 kg/ha of nitrogen, phosphorus, and potassium, respectively.[10]

The results of these studies, presented in Table 3, indicate that with no vegetation the nitrogen recharge at a depth of 150 cm exceeded the amount added, indicating leaching of native nitrogen in addition to that added in wastewater. As indicated in Table 3, the perennial grasses were extremely effective in removing nitrogen from the wastewater while the legumes were somewhat less effective and the annual corn and sorghum varieties were least effective.

It appears that the growth of both grasses and annuals may have been nitrogen limited in that there was an increase in yield at the higher irrigation rates. With harvest, the grasses appeared to have effectively removed nitrogen throughout their active growth period from early spring until well into the fall. The annuals were not effective in nitrogen removal during the first seven weeks after planting, but during the period when they did take up nitrogen they were as effective as the perennial grasses. The perennial legumes were generally effective in removing nitrogen from the wastewater except for a short period immediately after harvest when root zone nitrate concentrations exceeded ten mg NO_3-N/ℓ. Since the legumes could fix nitrogen, they were not nitrogen limited but plant disease incidence increased with increased irrigation rate resulting in a decreased yield.

Phosphorus retention was excellent in all of the forage crop plots and no runoff was observed.[10]

Of the agronomic crops evaluated, the grasses offered the best nitrogen removal and the longest effective irrigation period. Legumes generally removed nitrogen adequately, but increased disease problems at the higher irrigation rates decreased both yield and nitrogen removal effectiveness indicating that they would be of greatest value at low rates of wastewater application. Efficient nitrogen removal by annuals was limited to a shorter period than was observed for the other crops thereby limiting the period of the year during which wastewater could be applied.

Winter Irrigation

Application of wastewater at a rate of five cm/wk to a three ha old-field plot of the WQMF for three winters proved that winter irrigation is feasible in Michigan.[11] Ice formation on the land insulated the soil and prevented significant frost penetration allowing excellent infiltration of wastewater throughout the winter. For the three winters of operation, wastewater infiltration ranged from 70 to 80 percent of that applied with the remainder running off the site.

With no vegetative uptake of nitrogen during the winter, the nitrate applied in the secondary effluent was not removed and leachate nitrate concentrations increased throughout the winter. Application of high nitrate wastewater during the winter would yield leachate nitrate levels exceeding ten mg NO_3-N/ℓ during most of the winter.

During the spring melt period, phosphorus concentrations in runoff water exceeded the Michigan phosphorus limit of one mg P/ℓ, but on balance throughout the winter excellent phosphorus removal occurred. For the winter irrigation period from December 1, 1976, to March 16, 1977, 77 percent of the phosphorus added remained on the site. Thirteen percent infiltrated to groundwater and only ten percent ran off[6] with the bulk of the runoff occurring during spring melt. The phosphorus runoff could be further reduced by minimal diking to prevent runoff during the period of early snow melt.

Winter irrigation of wastewater on old-fields in Michigan yields good phosphorus removal and is feasible if wastewater with a low nitrogen concentration is applied.

COMBINATION OF AQUATIC AND TERRESTRIAL SYSTEMS

Optimal operation of the WQMF for wastewater processing involves meshing the best features of the pond system with those of the various portions of the terrestrial site. Ponds are not effective in the removal of phosphorus from wastewater but yield excellent nitrogen removal. This inability of the ponds to remove sufficient phosphorus to meet effluent standards prohibits discharge from the ponds to surface waters. Phosphorus removal by the terrestrial site is extremely effective but nitrogen removal efficiency varies from excellent to poor with vegetative cover and time of year. The operational and management plan outlined below appears to offer the most effective use of the WQMF for wastewater management and is currently being initiated.

From April to October, the old-field vegetation effectively removes nitrogen yielding a potentially valuable harvestable crop. During this period the entire 1,892 m^3/day loading of secondary wastewater will be applied to old-fields with as little detention as possible in the ponds to maximize nitrogen recycle to harvestable old-field biomass. The water held in the ponds during this period will be subject to nitrogen removal. By mid-October, when the terrestrial vegetation ceases growth and no longer removes nitrogen, the ponds will contain sufficient low nitrogen water to allow irrigation throughout the winter. Since water will be withdrawn from the ponds at nitrate concentrations less than the ten mg NO_3-N/ℓ drinking water standard, nitrate contamination of the groundwater should not occur. The point of withdrawal of water for irrigation will be moved downstream from pond to pond as the continued addition of wastewater to the upstream ponds throughout the winter raises the nitrogen concentration of the water. During snow melt in March, the water-saturated land will infiltrate little additional water and irrigation will be curtailed with the wastewater entering the WQMF being stored in the ponds. With reinitiation of growth of the old-field vegetation in April, high nitrogen wastewater will again be irrigated from the head of the pond system. After the nitrogen content of the excess water stored in the ponds in March is reduced to levels below ten mg NO_3-N/ℓ, this water will be applied to the forest with no fear of contaminating the groundwater with nitrate.

Winter irrigation made possible by this combination of the best features of the ponds and the land yields a reduced requirement for both storage volume and land for irrigation, thereby allowing year around processing of 1,892 m^3/day of secondary wastewater on about 40 ha (100 acres) of the WQMF. Operation without winter irrigation would require significantly more land for both winter storage and summer irrigation yielding a substantial increase in both land acquisition and construction costs.

Management required for this operational plan is limited largely to harvest of vegetation in the irrigated fields. Harvest of the aquatic plants would not be necessary for the pond system to meet the wastewater management objectives since nitrogen is lost as ammonia during periods of intensive photosynthesis and is lost as nitrogen gas through denitrification during periods of respiration.

Aquatic plant harvest offers esthetic improvements in pond appearance and is essential to any attempt to maintain fish populations in the ponds. However, the prognosis for maintaining fish populations in the WQMF for the long term does not appear to be good. The tremendous nitrogen stripping ability of the ponds, which makes possible winter irrigation of wastewater, is also the prime factor limiting aquatic plant growth to forms which cannot be harvested to prevent fish kills. While fish production will be limited, operation of the WQMF in this fashion will provide nitrogen and phosphorus removal, recharge of high quality water to the groundwater, and maximum nutrient recycle in a manner approaching zero discharge to surface waters with substantial savings in land and construction costs compared to systems that store wastewater throughout the winter.

CONCLUSIONS

Experience with the WQMF to date suggests that the combined use of aquatic and terrestrial ecosystems offers considerable flexibility in designing systems for optimal reuse of wastewater through land application. For example, even though older forests do not efficiently remove nitrogen from wastewater, a suitable detention time in ponds would remove sufficient nitrogen to allow recharge of wastewater through older forests with no fear of nitrate contamination of the groundwater. In addition, application of low nitrogen water from the ponds to oldfields during the winter allows a reduction in the amount of land required for both irrigation and wastewater storage.

While the nitrogen stripping capacity of ponds allows wastewater application to land on which the vegetative cover is inefficient at nitrogen removal, it can limit both attempts to reuse wastewater nutrients and attempts to maintain harvestable fish populations in the ponds. Where the goal is to maximize wastewater nitrogen recycle through terrestrial crops, ponding of wastewater should be minimized, particularly during the summer months, to prevent nitrogen loss prior to land application. When wastewater is stored over the winter and applied to the land during the summer, considerable nitrogen loss will occur as a function of detention time in ponds, particularly during the warmer months of the year. Nitrogen limitation of aquatic plants to types which cannot be harvested allows accumulation of significant BOD which, when exerted, is detrimental to any fish in the pond.

Thus, while ecological mechanisms interact to limit the degree of multiple use of pond-land wastewater reuse systems, they do have much potential in wastewater management. In the design of pond-land wastewater processing systems the best features of the ponds should be meshed with the best features of the land to yield a system which meets specific needs for wastewater management and reuse relative to soil type, terrestrial vegetative cover and climate of the individual region.

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TABLE 1

Nitrogen Mass Balance for Forest and Old-Fields*

Treatment	Irrigation Rate (cm/wk)	Inorganic Nitrogen Input (kg N/ha)	Nitrogen Partioning (Percent of Inorganic Nitrogen Input)			
			Vegetation Removal	Runoff	Recharge	Retention
Forest	0	22	0	0	1	99
	5	190	0	0	85	15
	10	325	0	22	7	71
Old-Field (No Harvest)	0	22	0	0	1	99
	5	165	0	0	17	83
	10	286	0	0	42	58
Old-Field (One Harvest)	0	22	166	0	1	-67
	5	165	77	0	18	5
	10	286	51	0	27	22
Old-Field (Two Harvests)	0	22	315	0	1	-216
	5	165	94	0	6	0
	10	286	83	0	31	-14

*Modified from reference 6.

TABLE 2

Phosphorus Mass Balance for Forest and Old-Field*

Treatment	Irrigation Rate (cm/wk)	Total Phosphorus Input (kg P/ha)	Phosphorus Partioning (Percent of Total Phosphorus Input)			
			Vegetation Removal	Runoff	Recharge	Retention
Forest	0	0.17	0	59	1	94
	5	44	0	0	3	97
	10	87	0	33	1	66
Old-Field (No Harvest)	0	0.17	0	0	6	94
	5	33	0	0	1	99
	10	66	0	0	1	99
Old-Field (One Harvest)	0	0.17	5588	0	6	-5494
	5	33	43	0	1	56
	10	66	37	0	1	62
Old-Field (Two Harvests)	0	0.17	9176	0	6	-9082
	5	33	57	0	1	42
	10	66	41	0	1	58

*Modified from reference 6.

TABLE 3

Recharge to Groundwater of Wastewater Nitrogen Applied to Crops*

Irrigation Rate (cm/wk)	Inorganic Nitrogen** Input (kg N/ha)	Percent of Inorganic Nitrogen Input Recharged to Groundwater			
		No Vegetation***	Grass	Legumes	Annuals
2.5	102		6	15	22
5.0	155	177	6	25	57
7.5	208	104	4	35	78

*Modified from reference 10.

**Includes 22.4 kg N/ha added in fertilizer to all plots except the no vegetation plots and nitrogen added in both precipitation and wastewater irrigation.

***Total input for the no vegetation plots was 133 kg N/ha since they were not fertilized.

WETLANDS CREATION USING SECONDARY TREATED WASTEWATER

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During the past century, over eighty per cent of the wetlands within the San Francisco Bay region have been drained or filled to make way for agricultural, residential, industrial and other uses. In addition, massive diversions of fresh water to the Central Valley and Southern California threaten the remaining natural wetlands, particularly the upper reaches of the estuary, which are subject to reduced outflow of fresh water and increased salinity levels.

This loss of wetland habitat has resulted in greatly reduced wildlife and migratory waterfowl populations throughout the bay region. It has only been quite recently that the tremendous importance of wetlands as habitat and nursery for many of the aquatic organisms that support fish and wildlife has been recognized. Thus, protection, restoration and enhancement has been the subject of several research and demonstration programs in California and elsewhere.

In 1974 the Mt. View Sanitary District (MVSD), near Martinez, California initiated a full scale pilot wetlands enhancement program on low-lying reclaimed tidelands owned by the District. The objective of the program was to demonstrate the feasibility of utilizing plant effluent to create a wetlands environment for the benefit of wildlife and migratory waterfowl and to develop management techniques for improvement of both water quality and wildlife habitat.

The Water Quality Control Plan of the San Francisco Bay Basin states that all discharges must receive initial dilution of 10:1, except when the discharge is providing direct environmental benefits. In 1977 the San Francisco Bay Regional Water Quality Control Board, in recognition of the beneficial effects of marshlands on water quality and the demonstrated environmental benefits derived from the discharge of wastewaters to a marsh, adopted a marsh policy. This policy exempts wastewater discharges used for marshland reclamation and enhancement from the 10:1 dilution requirement and the prohibition of discharge to dead-end sloughs or shallow water areas of the bay. The District's wetlands creation project, operated for the benefit of local and migratory wildlife, allows it to maintain a shallow water discharge.

The concept of using treated sewage effluent as a freshwater source for the creation and restoration of wetland ecosystems also qualifies as an alternative wastewater management technology for meeting the objectives of the 1977 Clean Water Act Amendments promoting the use of land treatment processes that reclaim and reuse municipal wastewater. Wetlands reclamation projects are cost-effective and, depending on site conditions, energy requirements are minimal compared with landscape irrigation, agricultural, or industrial reclamation projects often requiring extensive pumping or additional treatment. Wetlands projects also are consistent with EPA's multiple use policy supporting wastewater management practices which combine open space, recreational and educational considerations with such management.

PHYSICAL FACILITIES DESCRIPTION

Treatment Plant

Mt. View Sanitary District was established in 1923. It serves a portion of the City of Martinez and unincorporated areas of Contra Costa County, with a present population of approximately 14,000. A primary treatment plant built in 1951 served the District until 1969 when secondary treatment facilities were constructed. The process provides two-stage biofiltration with separate sludge digestion. Facilities include comminution, primary and secondary clarifiers, a rock biofilter with a rotating dual distributor, recirculation pumps and chlorination facilities. Sludge handling facilities include grit removal, sludge thickening and primary and secondary sludge digestion. A belt-filter press and paved drying beds provide for sludge dewatering. The plant is designed to provide full secondary treatment for 1.6 mgd dry weather flow. Present dry weather flow is approximately .75 mgd (2839 m^3/d). Effluent consistently meets standard secondary treatment requirements of 30 mg/l biochemical oxygen demand and suspended solids. The effluent is disinfected by chlorination to meet a residual coliform requirement of 23 MPN/100 ml before entering the wetlands. Chlorine residual is reduced to 0.0 mg/l within the wetlands system.

Wetlands Facilities

Wetlands facilities cover 20.3 acres (8.2 ha) and consist of five interconnected areas with tributary edge habitat. The total plant flow passes through the ponds and marshes into Peyton Slough which discharges into tidal waters of Suisun Bay through a tide gate located about one mile north of the District plant. The wetland plots cover 15.2 acres (6.1 ha) with a capacity of 3.8 acre feet providing 4.8 days retention time at plant flow of 1.6 mgd. At present flow, retention time is approximately ten days.

As shown in Figure 1, plant effluent is conveyed by gravity through an outfall pipe and siphon under Peyton Slough to Plot D. The area is divided with earthen dikes into alternating shallow and deeper ponds. The shallow ponds will contain emergent vegetation while deeper areas will remain open water. Since a prime design objective is to provide a combination of open water and vegetated habitat, this method of channelization directs the flow through the vegetation and provides for circulation. The final cell of Plot D contains Ecofloats[1] which are strung across the open water. These devices are made of redwood bark, wood, and styrofoam for floatation. They provide supplemental artificial substrate or habitat for aquatic invertebrates which normally colonize the benthos or emergent vegetation. Thus, they increase the numbers of organisms which can live in open water.

The flow passes from the Ecofloat pond over weirs into Plots C and E. Marsh Plot E will be cultivated and planted to provide food for migratory waterfowl. Watergrass and alkali bulrush *(Echinochloa crusgalli* and *scirpus robustus)* will be planted. Since the District wetlands are located on the Pacific Flyway the possibility exists to feed many migratory waterfowl. Marsh Plot C is open water with four vegetation-covered islands which provide food, shelter and nesting sites.

The discharges from Plots C and E are combined and flow by gravity through the inverted siphon to the slough from which the flow is directed to both plots A-1 and B. Flow through the wetlands system is entirely by gravity. Dinges points out that high pressure pumps and excessive velocities should be avoided since they harm the delicate aquatic invertebrates which are so important to maintaining a balanced aquatic system.[2] The water level in each wetland plot is controlled by adjustable weirs.

Plots A-1, A-2, and B formed the original wetlands system whose objective was to compare creation of vegetated versus open water habitats, with the treated wastewater. It was determined that each type of habitat was successfully created and that the combination provided a more stable, total habitat than either type alone. Plot B is mixed open water and emergent vegetation. Plot A-1 contains emergents and A-2 is an open water area with supplemental invertebrate habitat. Large open water areas are particularly important in attracting migratory ducks; the area must be visible to the waterfowl while flying. The flow is discharged to Peyton Slough from Plots A-2 and B. Table 1 lists the size of each plot, the depth varies between 1' - 3' (.3-1m).

WATER QUALITY CHARACTERISTICS

The wetlands environment has a positive effect on the treatment plant effluent. Various monitoring programs have been carried out during the life of the project to assess the water quality within the wetlands and also the quality of water discharged from the system.[3] The local climate is mild, average daytime water temperature is 19° C, range 5 - 29° C. The pH normally remains between 7.0 - 7.4 units; increases up to 8.8 units occur accompanying algal blooms. APHA Standard Methods, 14th Edition procedures are followed for all analyses.

Dissolved Oxygen

The levels of dissolved oxygen (DO), measured with a portable meter, vary diurnally and seasonally from about 1.0 mg/l to supersaturation. Normally levels above 5 mg/l are maintained. Due to the shallow depths and frequent wind mixing, the dissolved oxygen levels do not become stratified. The highest amounts of DO are caused by algae and occur in the summer months. The lower levels of DO occur in the early morning hours. In general, the DO in winter months has a lower, smaller range. Even with the wide range of DO levels there have been no odor problems or anaerobic conditions associated with the wetlands.

Biochemical Oxygen Demand

Figure 2 shows biochemical oxygen demand (BOD) and suspended solids data in six-month intervals divided into growing season and non-growing season. The water quality in a biological system, such as the wetlands, is affected by the seasonal life processes occuring there. The BOD of the plant effluent has been consistently reduced by Marsh B; only in two six-month periods did the BOD remain the same as it was in the plant effluent. The A complex reduced the BOD in the winter months and the summer of 1977, but raised the BOD during the other two summers. It must be stressed, however, that the type of BOD leaving the treatment plant and that leaving the marsh system differ. Materials comprising the BOD in the plant effluent are the degradation products of human waste. The material exerting a BOD in the marsh effluent is partially composed of algae and other living organisms at the very base of the food chain. These constituents are ready to be used by organisms downstream, whereas the materials in the plant effluent are not yet in a usable form.

Suspended Solids

Suspended solids (SS) data for the four years to date show that in the strict sense, SS are usually reduced in the winters but not in the summer. When SS leaving the wetlands are higher than the values found for the plant effluent, it can usually be attributed to algal growth in the pond-like portion of the system or silt from winter run-off. Therefore, it is especially important to acknowledge the form in which the SS leave the wetlands because algae comprises the producer level of the food chain. This producer status means that the algae is the base of the food pyramid allowing a healthy, balanced ecosystem to occur in the marshes and slough.

Nutrients

Nutrient levels in the plant effluent are variously affected by the wetlands. In some cases nutrients are removed and in others, levels remain unchanged. The nutrient analyses were run on grab samples collected during 1975-1978, using standard methods. Table 2 gives the average, range and percentage of wetlands samples that had a lower level of the nutrient than did the plant effluent sample on the same day. Consistent nitrate removal is accomplished by the wetlands. Nitrification does not occur to any great extent. Phosphorus does not appear to be a limiting nutrient. The amount entering is also discharged. There is a great deal of biological activity in the wetlands. A balance seems to be achieved such that nutrients are neither added to nor extracted from the system. The exception to this is the consistent reduction of nitrate levels.

THE HABITAT

Numerous ponds, marshes and rivers in the United States are fed, in part, with treated wastewater. The unique aspects of this project are 1) a wetlands exists where previously there was none 2) the sole source of water is treated wastewater 3) the primary purpose for creating the wetlands is to provide wildlife habitat. The major goal of this research has been to define the components of this newly created wetland habitat. Only after defining what exists can one then proceed to determine success or failure of the project.

Vegetation

A wetlands community is complex and is composed of both terrestrial and aquatic forms of plants and animals. There are more than 67 species of macrophytes in the MVSD wetlands; none were planted by the District. Twelve of these are emergents: *Typha* spp., *Scirpus* spp. sedges; another ten are particularly saline tolerant, 29 are native to California. In the early 1800's the site was covered by a brackish water marsh, which was later diked and drained. This accounts for the saline nature of the soil. The remaining plants are field annuals, perennials, herbs and shrubs. The vegetation serves as food, shields animals from predators, provides nesting sites and improves some water quality parameters. Nineteen of the species have seeds that are used by waterfowl for food.[4] As winter progresses, food becomes more scarce and the birds and animals eat many plants or plant parts not otherwise eaten. Planting the 2.5 acre Plot E in seed producing vegetation will expand the available food supply.

An open water area mixed with stands of emergent vegetation provides the habitat necessary for a greater variety of organisms. This diversity provides for greater interdependence of plant and animal species leading to ecological stability. The surface area of the wetlands is approximately 63% open water combined with 37% covered by emergent vegetation. Voigts notes that this interspersed type of habitat fosters a great variety of aquatic invertebrates and also appears to attract the greatest variety of nesting birds.[5]

Algae. The algal growth in the wetlands is highly beneficial. It oxygenates the water, removes ammonia, and serves as a food source for small herbiverous animals such as the zooplankton. The wetlands system has never been plagued by the growth of nuisance algae: no filamentous mats, no bluegreens, no odor producers. The dominant algae present over a two-year period were euglenoids, chlamydomonids, chlorella-like, and naviculates. Light and dark bottle productivity analysis has been carried out over a two year period, gross productivity results are shown in Figure 3. The low temperatures and overcast conditions of winter keep productivity very low to non-existant. During the summers studied, 1977 and 1978, algal growth was cyclical. However, numbers of algal cells, therefore oxygen evolution, was much greater in 1978. This increased number of cells is accounted for by the decrease in zooplankton population and other algal predators. The decrease in the zooplankton was due to the increased number of mosquito fish (*Gambusia afinis*). This is a humanly created upset in the ecological balance of the wetlands. Marsh management techniques provided the increase in mosquito fish, which successfully eliminated mosquito breeding. However, it also had this marked effect on algal growth. During the fall of 1978 as many as 52 common and snowy egrets were feeding on the mosquito fish, in an eight acre (3.2 ha) area. Some of the excess fish were trapped by other local agencies. It is hoped that in the coming year a balance can again be reached between the numbers of fish and invertebrates.

Animals

Twenty-one species of animals live at the MVSD wetlands: ten species of mammals, four sp. of amphibians, four sp. of reptiles, three sp. of fish. Rask studied the south levee of Plot B and found heavy use of mice (*Mus musculus* and *Reithrodontomys megalotis*) and muskrats (*Ondatra zibethica*).[6] The animal list includes both herbivores and carnivores; many of the species reproduce and live solely on what exists in the man-made wetlands. All of these animals have come to the District on their own.

Birds. Eighty-five species of birds either live in or stop at the wetlands during migration. This is a very large variety for such a small area; clearly wetlands are critical in the San Francisco Bay area. Schulenburg estimates that 70% of California's wetlands have been lost to draining and filling, since the turn of the century.[7]

An approximate breakdown of species composition is 15 sp. of ducks, 32 sp. of water and shorebirds, 30 passerine species, and 6 sp. of raptors.[4] It appears that many of the migratory birds return each year. If it is not the same individuals, it is at least the same species returning at the same time each year. In some cases these birds are somewhat uncommon in the locality, which leads the author to believe it is the same flock returning, for example tri-colored blackbirds. There are two types of usage of the wetlands by migratory birds. Some flocks will stay only a few hours or less; other flocks will spend weeks or months at the wetlands before moving to their destination, usually Canada or Southern California. For example, a flock of approximately 90 ruddy ducks has been here for two months, whereas a pair of mallards spent only one morning. Predatory birds, for instance herons and hawks, need a large range and the MVSD wetlands is included in the territory they rely on for food. There are a number of bird families in which many generations have hatched, grown and reproduced entirely dependent on the wetlands. A successful nesting this spring, 1979, of cinnamon teal will be the fourth generation. The quality of the water and chemical content of the vegetation must be acceptable since it enables the organisms feeding on it to continually produce viable offspring. The available food supply appears to define the carrying capacity of the wetlands, for birds.

Aquatic Invertebrates. There are more than 34 species of aquatic invertebrates living in the wetlands: eight sp. of bugs and beetles, ten sp. of flies, seven other insects, five sp. of zooplankton, four sp. of non-insects.[4] Voigts, studying four marshes in Iowa, found the number of taxa present to be between 20-32, with a maximum of 43.[5] This is clear evidence that a species list of 34 is comparable to that found in other small wetland areas. It is probable that there are more species than have been identified of zooplankton, due to the difficulty of identification. Nearly all of these organisms exist in the wetlands in each of their life stages. For these organisms to be able to reproduce successfully, generation after generation, they have to be living in high quality water. The volume of invertebrates and the species diversity also are clear indicators that a stable ecosystem has been created. During the summer of 1977, up to 3.8 lbs./hr. (1.7 kg/hr.) of zooplankton, mostly *Daphnia*, were trapped in the outlet weir of Plot A-2. This is a considerable volume of food available for use by larger invertebrates and fish living within the wetlands and downstream.

WETLANDS MANAGEMENT

A well designed project reduces the amount of necessary maintenance. The major design objective is to create a balanced habitat and avoid nuisance situations. Much was gained during the first four years of operation of Plots A-1, A-2, and B. This knowledge was incorporated in the design of the three areas added in 1978.

Levees

All levees should be wide enough for vehicular traffic so they may be utilized for maintenance when necessary. Some levees are used on a regular basis, others are not and vegetation is allowed to cover them. These vegetation covered levees add to the habitat but provide access when needed. Levees should be at least 10 ft. (3m) wide, steep-sided, with 1.5 ft. freeboard, and compacted during construction. There are many wetlands organisms which tunnel in levees: muskrats, gophers, crayfish, and other small mammals. Therefore, proper levee design and construction is crucial to keeping maintenance needs minimal.

Erosion

Vegetation is the main form of erosion control and works quite well once established. A minimum of one spring and summer are needed before the vegetation can become established, without specific planting and cultivation. Vegetation is not sufficient around weirs, gates and pipes. These areas must be fortified with riprap. The District is furtunate in this respect because it is located en route to the local landfill and gets all its riprap free of charge.

Plot Design

By dividing the total area designated for the wetlands into plots, more habitat goals may be achieved. When a multiple plot system is created, flow variations are facilitated. This allows one plot to be isolated from the system in case of major maintenance needs. Multiple plots also allow depth variation. Depth is a key factor in habitat design: it will determine whether or not emergent vegetation will be present and will affect temperature and dissolved oxygen values. Plot shapes may vary, but small, constricted areas should be avoided as they would promote stagnation and vector problems. Deciding which groups of organisms are likely to inhabit the wetlands and knowing what conditions these organisms normally live under will determine the fundamental components of the design.

Vectors

Botulism. *Clostridium botulinum* is the cause of avian botulism and will not cause botulism in humans. It is, however, deadly to waterfowl and certain measures may be taken to avoid its occurrence. There have been no known cases of avian botulism at the MVSD wetlands. Avoiding anaerobic conditions by keeping the water circulating and maintaining the depth under 3 ft. (1m) is an important factor in botulism avoidance. Removal of floating organic debris which collects behind weirs and in corners is regularly done. Steep-sided levees, adjustable broad crested weirs for controlling water levels, conveying water by pipeline, and ability to shunt a plot out of service for draining, are also factors in the botulism avoidance program.

Mosquitoes. Mosquitoes lay eggs in water and the larvae grow there, undergoing metamorphosis to the adult form. To breathe, the larvae must hang from the surface film of the water, piercing it with their respiratory tubes to obtain oxygen. This knowledge of the mosquito life cycle and habitat needs helps the wetlands manager avoid mosquito breeding problems. Open water areas, subject to wind action and providing easy access for predators, limit mosquito production. Maintaining good circulation in vegetated areas provides for predator access and lessens mosquito production. These factors have been the key to MVSD's success in keeping mosquito production minimal in 1978. Figure 4 compares the numbers of adult female mosquitoes caught in a light trap monitored by the Contra Costa County Mosquito Abatement District.[8] The insects are collected and counted weekly. Analysis began in August of 1976. The drastic reduction in numbers of mosquitoes trapped in late summer of 1977 and all of 1978 was due to the transplanting of mosquito fish *Gambusia afinis* in the early summer of 1977. Fish were taken out of Peyton Slough and stocked in Plots A-1, A-2, and B. By the end of the summer their numbers had increased enough to have the mosquito larvae population greatly reduced. Enough of the fish wintered over such that in the spring of

1978 they multiplied quickly and soon had the mosquito population under control. The rise in numbers at the end of 1978 was due to water trapped on property adjacent to the District's. Good circulation and adequate numbers of predatory fish have allowed MVSD to operate a wetland project which does not produce vector problems.

COSTS AND BENEFITS

The capital cost of the entire 20.3 acre (8.2 ha) wetlands has been approximately $130,000. Average annual operation and maintenance costs are about $20,000. The vast majority of this is salaries. No pumping costs are associated with the gravity flow wetlands system. The amount of time necessary by personnel depends on the amount of monitoring required and on maintenance needs which vary seasonally and can be greatly reduced by careful design of both the hydraulics and physical features of the system.

Benefits of the wetlands system using treated wastewater include improved water quality, habitat creation or enhancement, and recreational and educational opportunities. The wetlands is MVSD's contribution to the community, and it receives heavy use. The recreational and educational benefits included in the wetlands are a good example of the intent of section 201(g)(6) of the Clean Water Act of 1977. "The Administrator shall not make grants...(for) treatment works unless the grant applicant has satisfactorily demonstrated to the Administrator that the applicant has analyzed the potential recreation and open space opportunities in the planning of the proposed treatment works." There are visitors of all types ranging from neighborhood children who look for animal tracks to organized group tours for college students and environmental groups. The District has hosted researchers, municipal officials, and nature photographers. The local Audubon Society gave the District an award for its work and has declared the wetlands to be one of the best birding areas in the county. The California Chapter of the Soil Conservation Society of America has also officially commended the District for its work on water reuse and habitat creation. There is broad recreational potential in this type of water reuse project. Table 3 delineates the hourly usage of the wetlands by the public.

A wetlands system also has income possibilities. For example, during the summer of 1978 there was an overabundance of mosquito fish in the ponds. The local mosquito abatement district seined fish out of the ponds for their use. A local wildlife rehabilitation center and museum collects fish as well as duckweed and invertebrates for animal food. The District could charge for the fish and other food products produced.[9] The possibility exists to sell crayfish for bait or aquatic invertebrates for tropical fish food.[10] An option for a large wetlands would be to rent a portion of it to a duck club for hunting.

CONCLUSIONS

The protection, restoration and enhancement of wetlands has become a national goal. The potential environmental benefits derived from utilizing treated municipal wastewater for wetland restoration and enhancement has been demonstrated by the Mt. View Sanitary District's wetlands project. The project also demonstrates a reuse method that combines wastewater and wildlife management for optimum results. Wetlands systems created and maintained with treated wastewater are cost-effective and low in energy requirements. In fact, solar energy is the primary element supporting the plants and higher organisms that remove pollutants from the wastewater.

(1) A balanced and healthy wetlands ecosystem, composed of pond and marsh areas, has been successfully created using secondary treated wastewater.

(2) The wildlife habitat actively supports 67 sp. of plants, 21 sp. of animals, 85 sp. of birds and 34 sp. of aquatic invertebrates.

(3) Mosquito breeding has been reduced to a minimum through the use of natural predators. Avian botulism and odors have been avoided.

(4) Redwood bark floats provide supplementary habitat for aquatic invertebrates, thereby increasing their populations in open water.

(5) Nitrate removal is consistent. BOD and SS removal is seasonal --if algae was not regarded as a component of SS they would then be consistently lowered.

(6) Public support for the wetlands is strong. Educational and recreational usage is considerable and increasing.

Compared with other treatment plants in the San Francisco Bay area Mt. View Sanitary District is relatively small. However, this should not lessen the value of the wetlands creation project. The habitat is beneficial to both the wildlife and the local residents. Most important of all is the belief that this concept can successfully be applied to other communities throughout the country.

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8. Mosquito light trap data courtesy of Chuck Beasley, PhD entomologist for the Contra Costa County Mosquito Abatement District.
9. COLEMEN, MARK S. et al. Aquaculture as a Means to Achieve Effluent Standards. Oklahoma State Dept. of Health. Exerpted from project reports and reprinted for: Hinde Engineering Co., P.O. Box 188, Highland Park, IL 60035.
10. Local tropical fish stores have shown an interest in buying packaged, sterile *Daphnia* for 40¢/2 ounces. Peak *Daphnia* production yields 3.8 lbs/hr.

TABLE 1

Wetland Habitat Acreages

Plot	Surface Area (*ac.*)	Edge Habitat (*ac.*)
A-1	1.2	0.3
A-2	4.0	1.0
B	3.1	0.9
C	2.2	0.7
D	1.7	0.6
E	2.5	0.9
Slough	0.5	0.8
Total	15.2	5.1

TABLE 2

Nutrient Levels

Nutrient	Average (*mg/l*) Effluent	A	B	Range (*mg/l*) Effluent	A and B	% Reductions[1] A	B
NO_3-N	7.4	3.3	1.7	.55-18	.06-16	90	97
NH_3-N	7.9	6.7	6.8	.24-15	.1 -19	60	56
Org-N	4.8	4.4	4.6	.4 -14	.09-17	56	63
PO4	9.9	9.1	10.0	.44-18	.48-18	53	37

[1] This is the percentage of samples when the marsh discharge was lower than the marsh influent, i.e. plant effluent.

TABLE 3

Public Usage of Wetlands (Hours)

Year	Education	Recreation	Total	Hours/Acre[1]
1977	292	280	572	52
1978	524	291	815	74

[1] Unexpanded system of 11 acres.

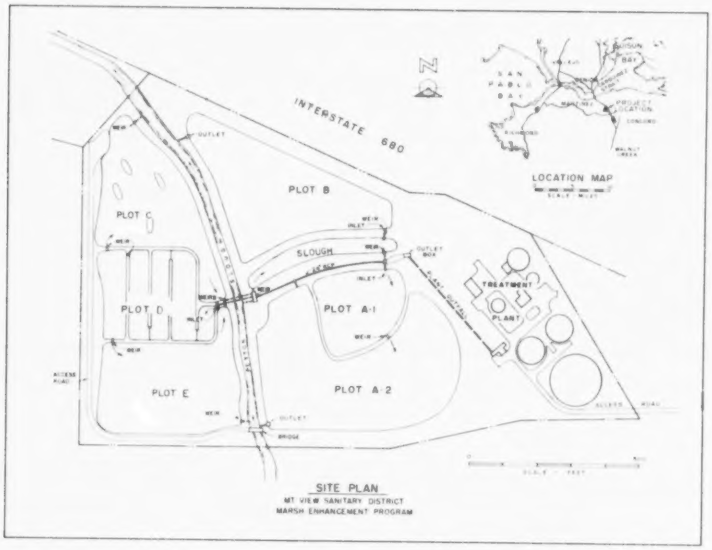

Figure 1 Wetlands Plot Plan

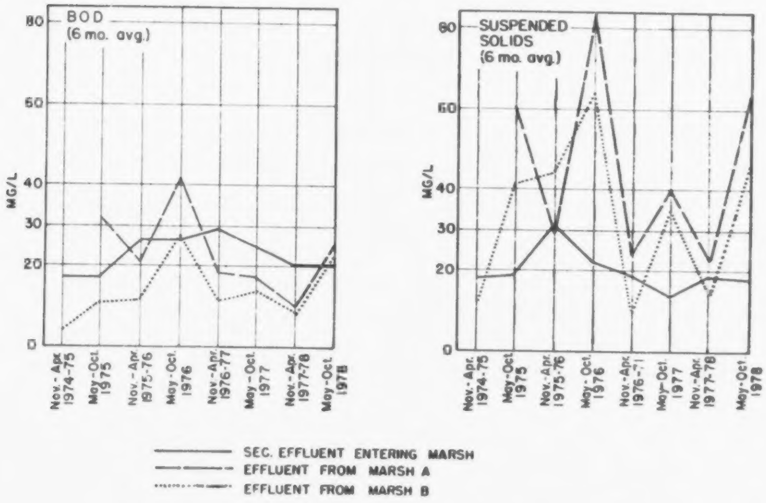

FIG. 2 Biochemical Oxygen Demand and Suspended Solids Data

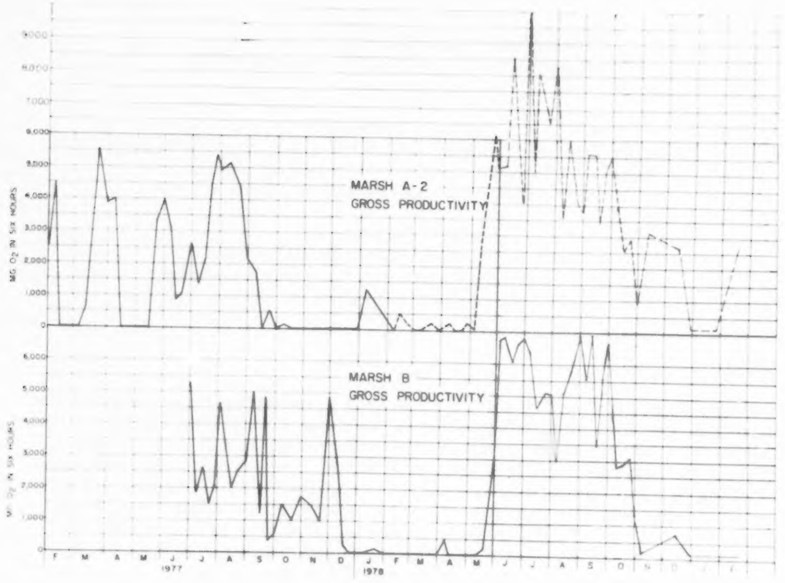

Figure 3 Algal Productivity

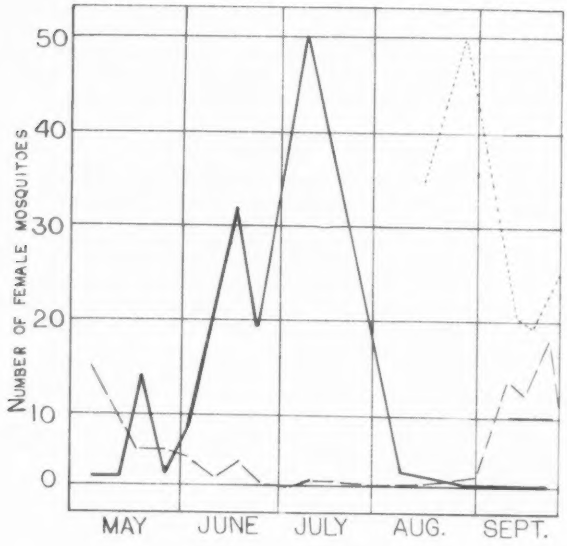

FIGURE 4

Mosquito Production

POTENTIAL OF AQUACULTURE FOR RECLAMATION OF MUNICIPAL WASTEWATER

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INTRODUCTION

Wastewater aquaculture is a viable research area having large potential for application to environmental problems. In order to develop reliable processes for wastewater treatment or reuse, however, it will be necessary to evaluate variations of criteria such as loading, pretreatment requirements, stocking and harvesting rates, product processing and utilization, acceptability of species, climatic factors, and economy of operation. Wastewater aquaculture is very broad in scope involving a variety of organisms, both freshwater and marine environments, organized treatment processes, and wastewater recycling by inputs into natural aquatic habitats.

Due to the broad scope of wastewater management by the aquaculture alternative, it becomes important to identify those areas where technological progress is sufficient to proceed with developmental or relatively low risk activities in terms of performance testing to establish process design criteria. Research needs, current status of development, and resource requirements are all important considerations for determining the potential of major areas of aquaculture for reclamation of municipal wastewaters.

AQUACULTURE PROGRAMS IN THE UNITED STATES

Interest and support for a variety of aquacultural activities are rapidly developing in the United States. Organizations having programs in aquaculture include the Federal Government, state governments, universities, research institutes, private industry, and regional councils and commissions. Components of twelve Departments and Agencies of the Federal Government are conducting aquacultural programs which are not oriented toward research and development. Activities include advisory and information services, technical assistance, regulatory responsibilities, loans or grants to industry, and education and training.

Research and development programs in aquaculture are being conducted by components of fourteen Departments and Agencies of the Federal Government. The variety of aquatic organisms being cultured in connection with these programs, as well as fifteen specific areas of research and development, are shown in Table 1. Although it is apparent that most of the programs support product oriented aquaculture, a significant number of programs are oriented toward wastewater aquaculture. Components of ten Departments and Agencies have programs in the wastewater utilization area involving the culture of a large variety of aquatic organisms (Table 2).

Several of the areas of aquaculture research and development, listed in Table 1, support both product oriented aquaculture and wastewater aquaculture. A description of the characteristics of these two types of systems helps to clarify their relative positions in terms of technology development. It should also be recognized that the possibility exists for a wide variety of combinations of product oriented and wastewater aquaculture systems.

PRODUCTION AQUACULTURE VS. TREATMENT PROCESS AQUACULTURE

In aquaculture systems that place primary emphasis on obtaining a valuable product, aquatic organisms are cultured under intensive or high population conditions. Water is provided from a non-waste source, and large inputs of feed and/or fertilizer are required. The primary concern in relation to water quality of effluents from these product oriented systems is usually based upon the amounts of wastes contributed by the metabolic processes of the organisms being cultured. Other waste sources, such as feed or fertilizer, which have not been fully utilized, and special chemical additions may, however, contribute significantly to changes in the quality of effluent from such systems.

Production is a secondary feature of aquaculture systems that emphasize the culture of organisms for wastewater treatment and management. Wastewater is utilized as the source of feed and nutrients for organisms being cultured. Conditions of culture are usually less intensive than those associated with product oriented systems. Both removal of pollutants and contribution of waste materials by the culture organisms must be considered in terms of water quality of the effluent.

The technology base available for aquaculture systems that place primary emphasis on obtaining a valuable product is much greater than the technology base available for systems that emphasize the culture of aquatic organisms for wastewater treatment and management. Several types of aquacultural systems, which are oriented toward production, have been developed to the point that they are considered to be in the advanced demonstration or application stage. Wastewater aquaculture is in the early stages of research and development. Although exploratory efforts are sufficient to indicate that several types of organisms and processes have potential for treating and utilizing inputs of wastewater, information available at this time is not adequate for design of reliable wastewater aquaculture systems.*

DEVELOPMENTAL POTENTIAL OF MAJOR AQUACULTURAL AREAS

A technical advisory group was established to aid in objectively assessing the potential for development of municipal wastewater aquaculture. All 33 members of the group had been involved to some extent in wastewater aquaculture, and many are considered experts in specific areas of this field. The group consisting of scientists, engineers, and program managers represents a diversity of organizational units including state and federal agencies, educational institutions, research institutes, and engineering consulting firms. The tasks performed by the technical advisory group consisted of identifying research needs, establishing priority among major areas, and determining research status for specific needs and resource requirements.

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*Duffer, William R. and James E. Moyer. Municipal Wastewater Aquaculture. EPA-600/2-78-110. U. S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, June 1978. 47 pp.

Research Needs and Their Priority

Within the major aquacultural categories considered, a total of 45 specific research needs were identified. In assigning priority ranking to major aquaculture categories and specific research needs within categories, technical advisory group participants considered the present level of accomplishment, as well as the potential for an early pay off in terms of development of municipal wastewater treatment technology. The priority ranking of major research areas in descending order was aquatic macrophytes, wetlands, food chain processes, economic evaluation, finfish, and invertebrates. Ranking values for the eight identified research needs in the aquatic macrophyte category are shown in Table 3. The research need which was considered the most important has an assigned numerical value of 1; the next most important, a value of 2; etc.

Research Status

Determination of research status for specific needs is based on exploratory, developmental, and demonstration as research types representing a progressive sequence of accomplishment. Research status definitions are provided in Table 4. The results of the research status effort are summarized by major aquacultural areas (Table 5). Thirty of the specific research needs were considered to be exploratory, and the remaining fifteen were considered to be developmental. None of the 45 specific research needs were assigned to the demonstration category.

If a more specific definition of research types were considered with initial and advanced stages for each category, the resulting assignments provide greater insight to research status. In the exploratory category, only two research needs were considered to be initial exploratory, while 28 were considered to be advanced exploratory. In the developmental category, thirteen were considered to be initial developmental, and two considered to be advanced developmental.

The research status for specific needs in the aquatic macrophyte area (Table 3) can be grouped into three stages. Research needs with priority rankings of one, four, five, and eight are in the advanced exploratory stage. Research needs with priority rankings of six and seven are in the initial developmental stage, while those with priority rankings of two and three are in the advanced developmental stage.

Resource Requirements

Estimates of the resources required to advance present technology are summarized for major aquacultural areas and projected in both man-years and total costs (Table 6). One man-year was considered to be equivalent to $35,000 in terms of total project costs. Resources required to advance technology are listed for one level and two levels beyond the present research status. These levels are defined as initial and advanced stages for each of the research categories defined in Table 4. For example, if one considers the present status of a specific research need to be advanced exploratory, initial developmental is one level forward, and advanced developmental is two levels forward.

Resource requirements for specific research needs in the aquatic macrophyte area are shown in Table 7. Distribution of resources to advance technology for specific research needs among other major areas of aquaculture followed a similar pattern.

SUMMARY

Based on available technology and potential for early pay off, the current research and development effort should be concentrated in two major aquacultural areas--aquatic macrophytes and wetlands. Development of water hyacinth wastewater treatment systems is the most advanced, especially in terms of low levels of organic loading. Additional developmental activities which are needed in the aquatic macrophyte area include evaluation of a variety of species, testing of environmental control and high levels of organic loadings for water hyacinth, and utilization and processing of products. In the wetlands area, evaluation of the treatment effectiveness of artificial or structured wetlands should be emphasized. Some attention should be given, however, to inputs of wastewater into natural wetlands.

TABLE 1*

Federal Aquaculture Programs in Research and Development

Major Research and Development Area	Separate Organizational Components	Culture Organism Groups
1. Life History & General Biology	4	8
2. Growth, Physiology, & Behavior	5	9
3. Genetic Reproduction & Selective Breeding	6	>15
4. Disease & Mortality Control	5	>16
5. Nutrition & Feeds	8	>20
6. Environmental Requirements	7	>22
7. Wastewater Utilization	10	>16
8. Culture Systems	9	>19
9. Culture Techniques	7	>29
10. Polyculture Systems	5	> 3
11. Pilot Scale Tests	2	6
12. Harvesting, Processing, & Product Quality	4	> 9
13. Economic Analysis	5	>13
14. Marketing Studies	2	7
15. Regulatory, Legal, & Institutional Constraints	1	> 2

*Adapted from Planning Panel of Interagency Committee on Marine Science and Engineers Subcommittee on Aquaculture, March, 24, 1978.

TABLE 2*

Federal Aquacultural Programs in Research and Development--Wastewater Utilization Area

Agriculture-CSRS	Catfish, Miscellaneous Freshwater Fish, Mixed Species Finfish, Clams
Agriculture-SAES	Lobster, Flowering Plants
Commerce-NMFS	Catfish
Commerce-OSG	Pacific Salmon, Lobster, Oysters, Mussels, Mixed Species Molluscs, Mixed Animal Species/General, Unicellular Algae
Interior-FWS	Clams
Interior-OWRT	Mixed Species Finfish, Lobster, Mixed Animal Species/General, Attached Algae
National Science Foundation-RANN	Trout, Freshwater Prawns, Lobster
Environmental Protection Agency	Mussels, Carp, Miscellaneous Freshwater Fish, Flowering Plants
Tennessee Valley Authority	Miscellaneous Freshwater Fish, Clams
NASA	Flowering Plants

*Adapted from Planning Panel Report of Interagency Committee on Marine Science and Engineers Subcommittee on Aquaculture, March 24, 1978.

TABLE 3

Specific Research Needs and Their Priority for the Aquatic Macrophyte Area

1. Test treatment effectiveness of vascular aquatic plants in existing sewage oxidation ponds and as pond units following sewage oxidation systems. Factors to be considered include odor control, winter protection of plants, nutrient uptake and growth rates, screening a variety of plants, comparative economic studies, water hyacinth demonstration facilities, and design for both secondary and tertiary standards.

2. Test a variety of macrophytes for wastewater treatment effectiveness, climatic limitations, commercial uses, and yield. Included among these are duckweed, cattails, reeds, rushes, and submerged aquatics.

3. Test treatment effectiveness of utilizing water hyacinth for upgrading the effluent from conventional sewage treatment plants. Items studied would be comparative economic feasibility, controlled environment for winter culture of plants, harvesting and utilization, energy requirements, treatment effectiveness design features, system control mechanisms, altering nutrient balance, and selection and plant breeding.

4. Test water hyacinth and macroscopic algal systems in combination with other organisms as a polyculture system. Research would be oriented toward extending the treatment effectiveness and increasing the economic return through sale of more valuable products.

TABLE 3 (Continued)

5. Test a large variety of aquatic macrophytes for uptake of materials believed to be toxic or of concern to human health such as heavy metals, halogenated organics, and chemical species which are known or suspected to be carcinogenic, teratogenic, or mutagenic. Uptake, screening, and breeding experiments, as well as engineering feasibility studies, would be performed.

6. Test treatment effectiveness of utilizing algae (seaweeds and freshwater filamentous algae) for treating municipal wastewater. Research areas are comparative economic evaluation and engineering feasibility, treatment effectiveness design, harvesting and utilization, and energy requirements.

7. Utilize aquatic macrophytes to reclaim water of potable quality and nutrients in reuseable form from domestic wastewater. Closed systems would be tested for reclaiming of nutrients, extracting and metabolizing organic pollutants, and reclaiming potable water. General design criteria would be developed.

8. Test treatment effectiveness of a wide range of non-aquatic plants utilizing an intensive hydroponic culture system. Research would emphasize non-food crops of high value such an ornamentals. Pretreatment would be evaluated and experiments are suggested in at least four types of areas--temperature, soft water; temperature, hard water; subtropical, soft water; subtropical, hard water.

TABLE 4

Research Status Definitions

Exploratory	The process or system is proposed. Wastewater techniques may or may not be established. Research effort is oriented toward determining feasibility for wastewater treatment or utilization.
Developmental	Involves testing to establish design criteria for aquacultural processes. Includes evaluation of pretreatment requirements, optimizing system stability, and determining treatment effectiveness under variable conditions.
Demonstration	Preliminary design criteria are available and are utilized to construct large-scale operational systems.

TABLE 5

Aquaculture Research Needs by Major Area and Research Type

Aquacultural Area	Research Type	Number of Specific Research Needs
1. Aquatic Macrophytes	Exploratory	4
	Developmental	4
2. Wetlands	Exploratory	3
	Developmental	3
3. Food Chain Processes	Exploratory	6
	Developmental	2
4. Economic Evaluation	Exploratory	6
	Developmental	2
5. Finfish	Exploratory	4
	Developmental	3
6. Aquatic Invertebrates	Exploratory	7
	Developmental	1
All Areas	Exploratory	30
	Developmental	15

TABLE 6

Estimate of Resources Required to Advance Research Needs

MAJOR AREA	RESOURCES			
	Man-Years		$1,000	
	One Level	Two Levels	One Level	Two Levels
Aquatic Macrophytes (8)	71	135	2,485	4,725
Wetlands (6)	55	93	1,925	3,255
Food Chain Processes (8)	68	123	2,380	4,305
Economic Evaluation (8)	42	78	1,470	2,730
Finfish (7)	59	116	2,065	4,060
Aquatic Invertebrates (8)	60	107	2,100	3,745
Total (45)	355	652	12,425	22,820

TABLE 7

Resources Required to Address Specific Research Needs in the Aquatic Macrophyte Area

Priority Ranking	Resources (Man-Years)	
	One Level	Two Levels
1	12	22
2	8	15
3	9	17
4	9	17
5	7	13
6	8	17
7	10	18
8	8	16
Total	71	135

PILOT STUDIES OF THE SOLAR AQUACELL CONTROLLED AQUACULTURE PROCESS FOR WASTEWATER RECLAMATION

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The use of aquaculture processes for wastewater treatment and reclamation is receiving increased attention because of the numerous potential advantages which ecological treatment systems have over conventional high technology processes. The Clean Water Act of 1977 mandates that "innovative and alternative" treatment technologies (specifically including aquaculture) which can save energy, chemicals, or costs must be evaluated as a treatment alternative before federal funding will be approved for any wastewater treatment system.

ADVANTAGES OF AQUACULTURE TREATMENT PROCESSES

The major advantages of aquaculture treatment processes are low operation and maintenance costs and simplicity of operation. Henderson and Wert (1) have calculated that aquacultural wastewater treatment systems can save up to 90% of the total life cycle treatment costs when compared to conventional technologies. To date, the most promising aquaculture wastewater treatment systems have used floating aquatic macrophytes, primarily water hyacinths and duckweeds, for upgrading conventional lagoons or acting as final "polishing" ponds (2-5). Duffer and Moyer (6) provide an excellent review of the status and potential of aquaculture processes for municipal wastewater treatment.

For wastewater reuse purposes, managed aquaculture systems offer the advantages of high dilution of toxic wastes along with increased retention times to reduce upset potential. Potentially toxic wastes can also be removed without addition of chemicals (2,3).

The chief limitations of most aquaculture type processes are high land area requirements and/or lack of process control for achieving advanced treatment objectives. Consequently, conventional high technology methods involving complex process trains have been the main method for advanced wastewater treatment. However, the assumption that these higher technology methods could achieve advanced wastewater treatment in a more reliable and cost effective manner needs serious reconsideration. Recent studies by EPA and the Government Accounting Office (7) have shown nearly all existing advanced wastewater treatment facilities are unable to meet either discharge or design criteria on a reliable basis. Even conventional secondary quality treatment plants failed to meet discharge or design criteria 30-50% of the time (8). In most cases the failure stemmed from the tight process control and short retention time design aspects of high technology processes, leaving them highly vulnerable to operator or mechanical failure and upset.

THE SOLAR AQUACELL TREATMENT SYSTEM

In order to provide an alternative between the extremes of existing high technology and algae lagoon methods, Solar AquaSystems, Inc. developed a high rate, controlled environment aquaculture process called the Solar AquaCell System.

The basic design parameters have been described previously (9) and in a separate article in this publication (10). The design principles of this system are based on an integration of the best features of lagoon systems (i.e., low operation and maintenance costs, low energy needs, high dilution factors, and toxin removal capabilities) with the reduced land requirements, greater process control, and advanced treatment capability of conventional high technology systems.

The process integrates the following major elements: 1) the basic multicell lagoon process; 2) the use of floating aquatic macrophytes, particularly water hyacinths and duckweeds; 3) greenhouse covered ponds to provide insulation and transfer of solar heat to the water; 4) high surface area fixed-film substrates (Activated Bio-Web Substrates) to provide habitat for the bio-film and associated invertebrate detritivore community; and 5) a dual aeration and solar heat exchange system for maintaining proper dissolved oxygen concentration, transfering solar heat from the air phase to the water phase in order to increase metabolic rates and treatment efficiencies, and providing for gentle stirring and partial mixing of the wastewater past the aquatic plant surface area and the Bio-Web substrates (Fig. 1).

This report describes results obtained during the past year's operation of an experimental demonstration facility using the Solar AquaCell process.

DESCRIPTION OF THE DEMONSTRATION FACILITY

The current Solar AquaCell demonstration unit is located at the San Elijo Treatment Facility in Cardiff, California. The San Elijo Treatment Facility is operated by the County of San Diego and provides primary treatment and ocean discharge of 2 million gals/day (7.6×10^5 m^3/day) of domestic sewage.

The Solar AquaCell Unit treats an average of 3,000 gpd/day (11,350 l/day) of either raw or primary treated wastewater from this site. It was designed to approximate full-scale lagoon design parameters in terms of surface to volume ratios, waste loading rates, aeration rates, and aquatic plant cover. It consists of a series of five cells operated by gravity flow (Fig.2).

The first two cells, designed for primary treatment of raw sewage, are anaerobic. The first cell (4500 l) acts as a sedimentation basin, but with upflow percolation through a sludge layer. The second cell (9000 l) contains vertically hanging "Activated Bio-Web Substrates", which function as fixed films to further reduce BOD, TSS, and increase methane production. Both anaerobic primary cells have floating rubber covers for methane gas collection and odor control. Total retention time for Cells 1 and 2 averages 12 hours.

The aerated AquaCell portion consists of three equally sized cells, each 2.4 m wide x 4 m long x 1.7 m deep and approximately 16,000 liter capacity. Total retention time for the five cell stream averages 4.5 days at the 3,000 gpd (11,350 l/day) flow rate. Diffused aeration is provided by a small air compressor and a submerged air diffuser pipe extending the length of each aerated cell. The first aerated cell (Cell #3) also contains a 0.06 hp surface aerator. Dissolved oxygen concentration was maintained at 1-3 ppm in Cell 3, and 3-6 ppm in Cells 4 and 5. Diffused aeration rates for Cells 4 and 5 are reduced to averages of 40 and 30 SCFH (20 & 14 l/min), respectively, to provide gentle mixing and final reduction of BOD.

Cell 3 is operated as a facultative treatment stage to ensure high sedimentation rates, maintain an anaerobic benthic layer for digestion of the deposited sludge, and reduce energy needs. Higher diffused aeration rates are applied to this stage (75-100 SCFH; 35-47 l/min.). No plant cover is used in this third cell in order to maximize surface oxygen exchange. Treatment is achieved primarily by sedimentation and microbial activity by the high surface area, buoyant, flexible, fixed-film substrates (Activated Bio-Web). The Bio-Web substrates provide a function similar to rocks or plastic media in conventional trickling filters or bio-disc processes, yet are designed to provide even higher surface area to waste loading ratios (0.1 m^2/liter/day).

Cells 4 and 5 are operated as high rate aerated lagoons to achieve various levels of advanced treatment. In addition to the submerged, Bio-Web Substrates, cells 4 and 5 contain floating aquatic plants, either water hyacinth (*Eichhornia crassipes*) and/or duckweeds (*Lemna sp.*, *Spirodela sp.*, *Wolffia spp.*). The plants function to shade out growth of planktonic algae, remove nutrients, trap suspended solids, and collect and remove a portion of the invertebrate food chain when harvested. The floating plants provide an additional advantage of resource recovery, since they are a convenient method for converting dissolved and particulate wastes into either methane gas, compost, or animal feeds.

A slow sand filter (4-8 l/min/m^2) at the effluent end of Cell 5 functions to trap any invertebrate organisms, aquatic plant debris or resuspended detritus exiting through the overflow pipe. The data on treatment presented in this paper does not include the sand filtration process.

The entire five cell series is enclosed within a greenhouse, which acts to insulate against heat loss while collecting solar heat, and maintaining higher winter operating temperatures. Water misting nozzles above Cells 3-5, spraying treated effluent water, serve to transfer the solar heat into the AquaCells to increase water temperatures, increase aquatic plant vigor and protect plants against overheating during summer periods.

DATA COLLECTION AND ANALYSIS

Data collection and analysis were performed by the University of San Diego Environmental Studies Laboratory. The performance analysis of the system was conducted jointly by the Applied Aquatic Resources Institute and the Environmental Studies Laboratory, funded in part by a contract from the U.S. Department of Interior, Office of Water Research and Technology (11).

The data presented in this report represents mean values from three discrete sampling periods:

Period	Date	Type of Influent	Type of Plant Cover
1	July - Oct.30 1978	Primary treated sewage into Cell 3.	Hyacinths
2	Nov.6-Dec.1 1978	Raw Sewage into Cell 1.	Hyacinths
3	Dec.5, 1978-Mar.5, 1979	Raw Sewage into Cell 1.	Duckweeds

Wastewater analysis was performed using EPA approved standard methods. A total of fifty-two sampling periods were conducted, usually twice a week, during the eight month period. A total of 1,008 chemical analyses were made including 240 for BOD, 230 for TSS, and 265 for nitrogen.

RESULTS AND DISCUSSION

Primary Treatment

The Solar AquaCell process can operate effectively with raw sewage directly entering the aerobic AquaCells. In order to reduce the energy required to digest the high strength raw sewage aerobically, it is preferable not to have aquatic plants inhibiting surface exchange of oxygen, and to reduce the oxygen demand of settleable solids by anaerobically, rather than aerobic means, during the first 0.5 to 1.5 days retention.

In this demonstration, use of the two stage anaerobic AquaCells for primary treatment reduced the energy requirements for pretreatment to zero and further reduced aeration energy requirements for achieving secondary quality effluent in Cell 3. The anaerobic AquaCell reduced raw sewage BOD levels by an average of 49% and suspended solids by an average 88% (Table 1, Figs. 3,4). In addition, use of the anaerobic upflow contact process does away with the need for separate sludge digestion tanks and associated energy and handling costs. Sludge digestion, taking place in the contact tank, has proven to be very effective. Methane gas is being produced in both cells, and studies are in progress to determine rates and composition.

Secondary Treatment

Raw sewage introduced into Cell 1 was consistently treated (95% of samples) to secondary quality by the end of Cell 3 as shown in Figures 2 and 3. This is equivalent to a total of 2.0 days retention time. With primary effluent from the San Elijo Facility (introduced into Cell 3) secondary standards were achieved after 1.8 days. It is interesting to note that secondary treatment was consistently achieved with the use of only the Bio-Web substrates and aeration and without any aquatic plants.

The Bio-Web substrates in both the anaerobic cell and aerobic cells provided treatment by a combination of the following functions (Fig. 1):

a) accelerating the agglomeration and sedimentation of suspended solids, thereby reducing both BOD and TSS.

b) increasing the active bio-film surface area for direct uptake and metabolism of nutrients by anaerobic and aerobic bacteria. Because the Bio-Web substrates are made of flexible, vertically suspended films, a steady sloughing off of bacteria and accumulated detritus occurred without need for any maintenance or mechanical removal.

c) any settleable solids resuspended by mixing or anaerobic gas formation in benthic layers quickly release attached gas bubbles and resettle when contacting the substrates.

Tertiary Treatment

Biochemical oxygen demand and total suspended solids continued to decline in a fairly steady manner with increased retention time. With water hyacinths as the plant component, BOD and TSS levels below 5 ppm could be reliably achieved within 4.5 days retention time. Use of duckweeds in place of hyacinths resulted in slightly decreased treatment efficiencies, indicating an additional 20-30% greater retention time might be needed to achieve the same treatment objective (Figs. 3,4).

Nitrogen treatment and removal proceeded steadily through the five cell system, as shown in Table 2 and Figure 5. Nitrification of ammonia to nitrate occurred at a consistant rate in Cells 3-5, primarily by the bio-film processes. Total Kjeldahl nitrogen and total nitrogen in all forms were removed fairly rapidly by all cells of the system, suggesting that levels below 5.0 ppm could be achieved within 8-10 days retention time. Additional studies under longer retention time situations will be required to determine nitrogen removal rates at lower concentration levels. It is interesting to note that total nitrogen occurring with the use of duckweeds was only 10% less than with hyacinths. Presumably this is due in part to duckweeds containing more nitrogen (ave. 40% protein), compared to hyacinths (ave. 20% protein), even though the hyacinths produced 3-4 times greater biomass per unit time (12,2).

The percentage of total nitrogen removed by the aquatic plants is surprisingly small in comparison to other pathways within the AquaCells (bacterial, invertebrate, and detritus food chains via the Bio-Web and sedimentation and anaerobic denitrification of solids). Preliminary studies indicate that a year-round average of 18 g/day of nitrogen was removed by water hyacinths in Cells 4 and 5 combined. Yet an average total of 182 grams of nitrogen/day was removed in passage through Cells 4 and 5, indicating 90% of the nitrogen was removed by the Bio-Web food chain and anaerobic processes. These results are substantiated by similar figures reported in a previous study on nitrogen balance in a closed-cycle aquaculture system using fixed films and aquatic macrophytes (13).

Phosphate removal rates have been relatively low, ranging from only 1 to 2 ppm during the four day retention period. This is as expected since the phosphorus demand of aquatic plants, bacteria and invertebrates is only one fourteenth to one twentieth that of nitrogen.

Natural reduction of total coliforms occurred rapidly in passage through the system, dropping from average influent levels of 80×10^6, down to 0.01×10^6/100 ml. within 4.5 days. Additional studies on byproduct contamination by pathogens, heavy metals and chlorinated hydrocarbons are in progress.

Total dissolved salts can increase substantially in uncovered lagoon treatment systems, particularly so with evapotranspiration if aquatic plants are used. TDS was examined only briefly during this study (using duckweeds) and showed no increase or decrease during the 4.5 day flow. Limited data from the previous Solana Beach AquaCell unit indicated reduction ranging from about 0-300 ppm (0-30%), but results were highly variable. Dinges (3) reported average TDS reductions up to 50% in a water hyacinth channel receiving secondary treated sewage. The biomass mineral uptake cannot account for more than 100 ppm or so of salts. Humic acids are produced during the breakdown of aquatic macrophytes in the benthic layer and were present in Cells 4 and 5. Chelation/humic colloid precipitation processes are well known (14) and probably account for this variable but potentially very useful process for TDS reduction.

Aquatic Plants

Water hyacinth biomass density was maintained between 12-15 kg/m^2 during the study. By regular harvesting and maintenance of the hyacinths at this density, intertwining of the plants did not occur to the point of interfering with harvesting. Net biomass production averaged 25 gms, dry wt/m^2/day. Duckweed biomass, when used as the exclusive macrophyte in the system, was maintained at standing crop densities between 1,000-4,000 gms, dry wt/m^2/day. Net production levels averaged 5.0 grams dry wt/m^2/day, based on a once per week harvest schedule. Seasonal variaton in productivity did not vary over a factor of 0.6 for either macrophyte because of the fairly constant environmental conditions maintained by the greenhouse enclosure. Without this cover the water hyacinths would have died back substantially (as occurred with hyacinths maintained in tanks outside the greenhouse), thereby contributing to the BOD, S.S., and nitrogen load on the system.

Although duckweeds are not as effective as water hyacinths in reducing BOD, S.S. and removing nutrients due to their lower growth rates and absence of a large fiberous root system, they have certain important advantages. They can be harvested more readily and without need for entering the pond by use of a slotted overflow weir and separation screen. Chopping is not necessary, and their reuse as a feed supplement is superior due to the higher protein levels (40% protein when cultured in high nutrient solutions) (12).

The biological film of bacteria, diatoms, algae, and detritus growing on the Bio-Web substrates in the 3rd Cell averaged 0.9 mm in thickness while Cells 4 and 5 averaged 0.2 mm and 0.1 mm, respectively. At no time did the bio-film build up much beyond this level. Natural sloughing and/or grazing by the invertebrates eliminated need for any maintenance. Quantification of detritivore populations has not been completed to date, but analysis of the microorganism populations indicated that while the density of organisms is greater in Cell 3, the diversity was greater in the 4th and 5th cells as the water became progressively cleaner.

Sludge accumulation in the aerobic cells has been low, due in part to the high solids removal efficiency of the anaerobic cells and the aquatic plant roots, and the maintenance of a benthic anaerobic digestion layer in the aerobic cells. Solids accumuation has averaged about 10 mm in Cell 3, and 5 mm in Cells 4 and 5 after nine months.

Energy Considerations

Aeration requirements of the Solar AquaCell process were determined by using air flow metering devices. Based on aeration volume requirements, and using average oxygen transfer efficiencies, the authors estimate an average of 15 connected hp/MGD [15.2 hp (m)/ 3.8 x 10^3 m^3/d] will be required to achieve secondary quality effluent, and 25 connected hp/MGD [25.4 hp (m)/3.8 x 10^3 m^3/d] to achieve advanced tertiary quality effluent.

In terms of energy requirements, the AquaCell process is similar to an aerated lagoon. Under conditions of high BOD, ammonia, and water temperature, it can require more aeration, primarily due to more complete nitrification and BOD reduction and the production of advanced tertiary rather than secondary quality water. The results to date suggest the process requires considerably less energy than theoretical estimates, based on carbonaceous and nitrogenous BOD, would indicate. This is due to the number of biological, physical and chemical processes which do not require oxygen occurring simultaneously within the three cell zones, as shown in Fig. 2.

Other process energy requirements which include harvesting of the aquatic plants, solar heat transfer spraying, and possibly biannual sludge pumping from the anaerobic digestor are all minor when compared to the continuous energy requirements for aeration.

CONCLUSION

The results of this study suggest that the functioning of the AquaCell system is a stable and linear process. The water quality improves in direct relation to retention time. This is in contrast to most lagoon processes which are subject to the fluctuating and often opposing processes of sedimentation, clarification, algae growth and die-off, nutrient release and regrowth, and so on, until eventual net stabilization of organic matter is achieved ofter 50-150 days retention time.

Due to the stability, reliability, and relatively low costs, this process should provide an excellent alternative to high technology or simple lagoon processes where water reuse is the desired objective.

ACKNOWLEDGEMENTS

The monitoring, sampling and chemistry analysis of the Cardiff AquaCell facility was carried out by Jeannie O'Toole and Dan Todd of the Environmental Studies Laboratory, University of San Diego. This work has been supported in part by Contract #14-34-0017817 from the Office of Water Research and Technology, U.S. Department of Interior and Contract # EM-78-G-03-1948 from the U.S. Department of Energy. Appreciation is extended to the County of San Diego, Department of Sanitation and Flood Control, for use of the Cardiff Treatment Facility site.

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Table 1. Treatment efficiency of selected parameters of the two-stage anaerobic primary treatment tank -- Cardiff AquaCell Demonstration Facility.

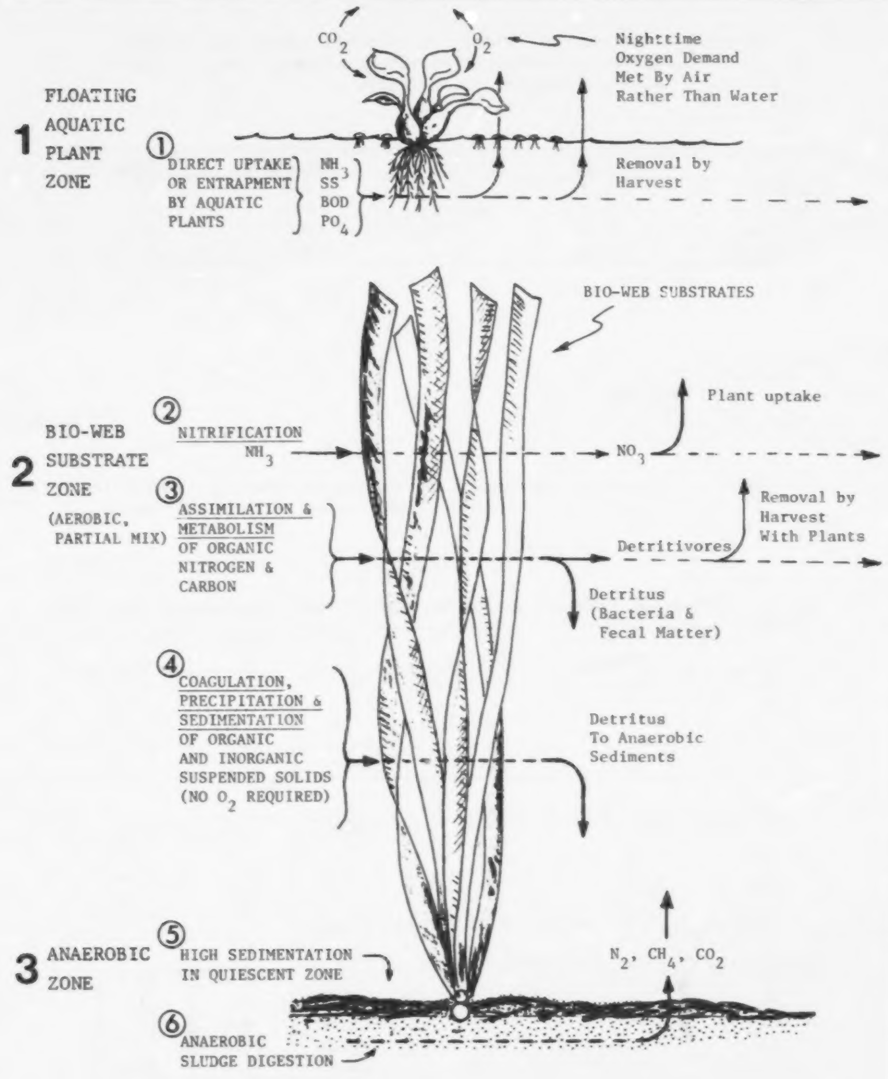
	Influent	Effluent	% Reduction	# of Samples
S.S.	265.0	35.0	88%	33
BOD	225.0	115.0	49%	27
Ammonia	41.8	37.4	10%	30
Turbidity	212.0	93.0	56%	13

Table 2. Nitrogen concentrations -- various chemical species in relation to treatment mode, retention time and season.

	Raw Influent	Cell 2 Effluent	Day 2	Day 3	Day 4
Hyacinths, July - Oct. 30, 1978					
NH_3	42.7	-	31.0	15.5	8.3
NO_2	0	-	0.1	0.8	1.2
NO_3	0	-	4.8	5.7	10.8
TKN	47.0	-	35.1	24.5	12.0
Total N	47.0	-	40.0	31.0	24.0
Hyacinths, Nov. 6 - Dec. 1, 1978					
NH_3	41.0	37.0	23.0	8.0	1.5
NO_2	0	0	0.7	1.0	1.4
NO_3	0	0	4.8	8.0	12.6
TKN	48.0	45.2	32.0	19.0	8.0
Total N	48.0	47.0	37.5	28.0	22.0
Duckweeds, Dec. 6, 1978 - Mar. 5, 1979					
NH_3	40.6	35.2	29.7	20.6	12.2
NO_2	0	0	0.2	0.7	1.3
NO_3	0	0	6.8	9.3	13.7
TKN	49.0	46.7	37.0	27.0	13.0
Total N	49.0	47.0	44.0	37.0	28.0

Figure 1. Chemical pathways of the Bio-Web Substrates.

THE SOLAR AQUACELL SYSTEM REDUCES OXYGEN & ENERGY REQUIREMENTS
BY INCREASING THE HARVESTING, SEDIMENTATION,
AND ANAEROBIC DIGESTION PROCESSES


CO_2
O_2
Nighttime Oxygen Demand Met By Air Rather Than Water
1 FLOATING AQUATIC PLANT ZONE
① DIRECT UPTAKE OR ENTRAPMENT BY AQUATIC PLANTS
NH_3
SS
BOD
PO_4
Removal by Harvest
BIO-WEB SUBSTRATES
Plant uptake
2 BIO-WEB SUBSTRATE ZONE
(AEROBIC, PARTIAL MIX)
② NITRIFICATION
NH_3
NO_3
③ ASSIMILATION & METABOLISM OF ORGANIC NITROGEN & CARBON
Removal by Harvest With Plants
Detritivores
Detritus (Bacteria & Fecal Matter)
④ COAGULATION, PRECIPITATION & SEDIMENTATION OF ORGANIC AND INORGANIC SUSPENDED SOLIDS (NO O_2 REQUIRED)
Detritus To Anaerobic Sediments
3 ANAEROBIC ZONE
⑤ HIGH SEDIMENTATION IN QUIESCENT ZONE
N_2, CH_4, CO_2
⑥ ANAEROBIC SLUDGE DIGESTION

PROCESS FLOW DIAGRAM - SOLAR AQUACELL DEMONSTRATION UNIT

Cardiff, California

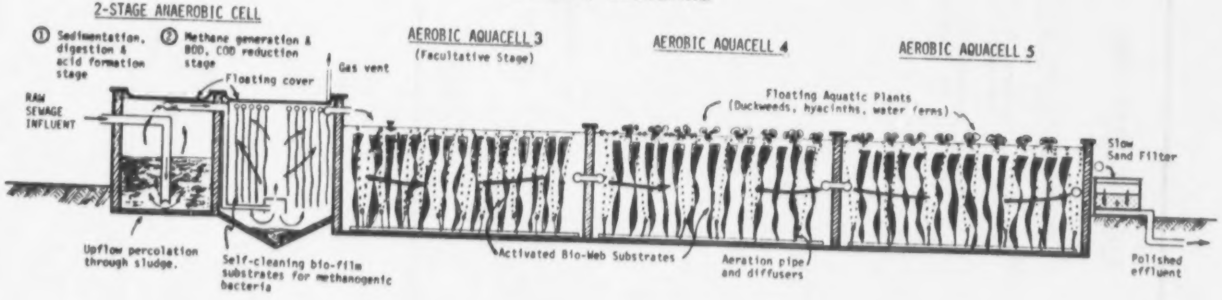

2-STAGE ANAEROBIC CELL
① Sedimentation, digestion & acid formation stage
② Methane generation & BOD, COD reduction stage
RAW SEWAGE INFLUENT
Floating cover
Gas vent
AEROBIC AQUACELL 3
(Facultative Stage)
AEROBIC AQUACELL 4
AEROBIC AQUACELL 5
Floating Aquatic Plants (Duckweeds, hyacinths, water ferns)
Slow Sand Filter
Upflow percolation through sludge.
Self-cleaning bio-film substrates for methanogenic bacteria
Activated Bio-Web Substrates
Aeration pipe and diffusers
Polished effluent

Figure 2. Process flow diagram. Solar AquaCell Demonstration Facility, Cardiff-By-The-Sea, California.

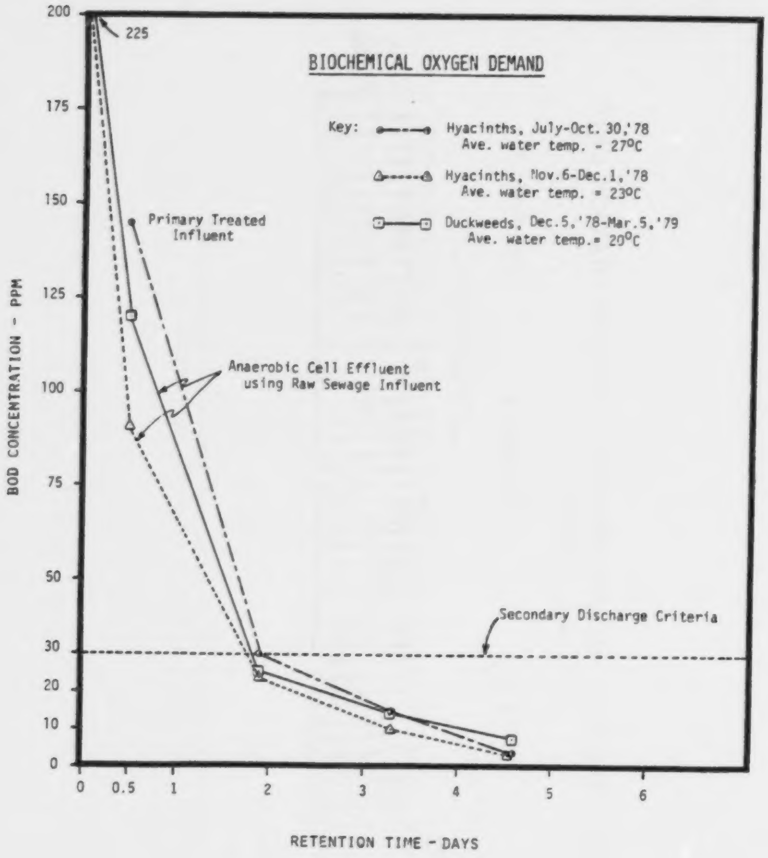


Figure 3. Biochemical oxygen demand (BOD_5) concentration as a function of retention time (DAYS) for the Cardiff AquaCells using water hyacinth or duckweed plant cover in Cells 4 and 5 (Days 2-4.5) at different times of the year.

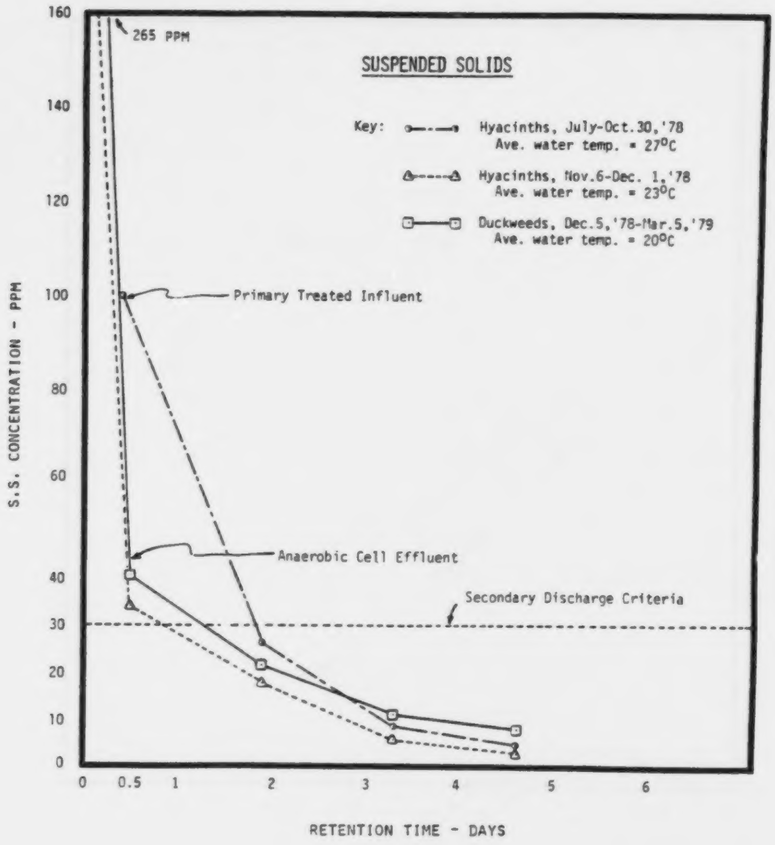


Figure 4. Suspended solids concentration in relation to retention time (DAYS) for the Cardiff AquaCell using water hyacinths or duckweed plant cover in Cells 4 and 5 (Days 2-4.5) at different times of the year.

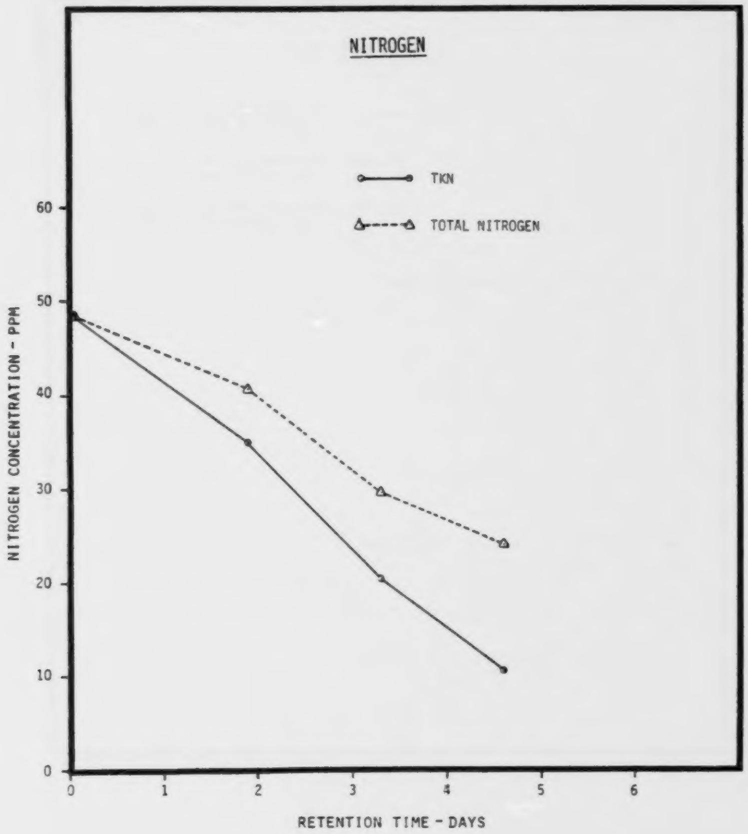
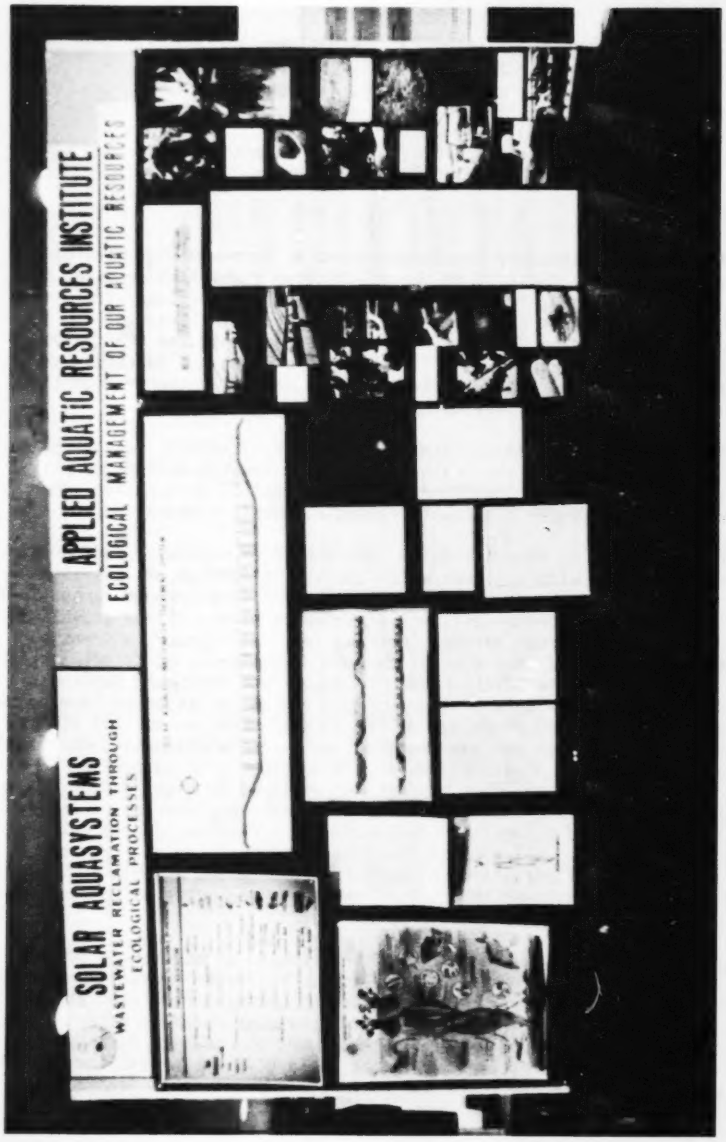


Figure 5. Nitrogen concentrations in relation to retention time for the Cardiff AquaCell using water hyacinth or duckweed plant cover in Cells 4 and 5 (Days 2-4.5); averages over the entire sampling period.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WASTEWATER RECLAMATION THROUGH
ECOLOGICAL PROCESSES

REUSE OF MUNICIPAL WASTEWATER BY VOLUNTEER FRESH-WATER WETLANDS

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Grand Rapids, Michigan

INTRODUCTION

The municipal wastewater treatment system at Vermontville, Michigan (population 975), consists of two facultative stabilization ponds of 10.9 acres (4.4 ha), followed by four diked surface (flood) irrigation fields of 11.5 acres (4.6 ha) constructed on silty-clayey soils. The system is located on a hill with the ponds uppermost and the fields at descending elevations (Figure 1). Now approaching the seventh year of operation, the fields are nearly overgrown with volunteer emergent aquatic vegetation, mainly cattail.

The Vermontville system is being studied (NSF ENV-20273, May, 1978) to identify and evaluate any features of the wastewater-wetland complex that would make it or something like it a feasible alternative among economical wastewater treatment systems for small communities.

Related studies by others involve interaction of natural runoff or sanitary wastewater with wetlands which operate as seepage or lateral flow-through systems. Spangler, *et al.* (1) studied flow-through removals of nutrients from secondary effluent effected in plastic-lined gravel-bedded artificial bulrush marshes (*Scirpus spp.)* at Seymour, Wisconsin. These workers found that most of the phosphorus taken up by bulrushes is stored in the microflora-substrate (roots and rhizomes) portion of the plant. Most of this phosphorus is given up in dissolved form by the plants in winter and flows out of the system. Lee, *et al.* (2) studied spring-fed and river and lake marginal wetlands in Wisconsin, and found that liberation of plant nutrients occurs probably in suspension of particles when natural flow through the wetlands is high. Bender, *et al.* (3) studied the fate of nutrients in Chesapeake Bay marshes using fertilizer tests and natural nutrient inflow and outflow. These authors found little or no net removal of either phosphorus or nitrogen and highest export of dissolved inorganic phosphorus and ammonia during the summer. They concluded that use of marshes of any type as nutrient removal systems is highly questionable.

Fritz, *et al.* (4) summarize some of the results of studies by others. Cypress dome and cypress strand wetlands, the former operating as seepage systems and the latter as flow-through systems, have been studied in Florida with tertiary treatment of wastewater, surface water retention and potable ground water recharge among the goals. Phosphorus and nitrogen applied in effluent at rates up to 0.75 in./wk (1.9 cm/wk) are removed from secondary level wastewater in cypress domes (seepage wetlands) before applied water reaches the water table. Cypress strands, which are diffuse fresh water streams with vegetated beds, seem to do a similarly effective job of nutrient removal where ample wetland (1000 acres per MGD [400 ha/3750 m^3]) is available to interact with secondary effluent.

Other flow-through studies include deliberate elements of wetland enhancement and wetland habitat development as goals of wastewater treatment. Kadlec, *et al.* (5) reported the results of five years of study of a nutrient-poor upland peatland (Houghton Lake, MI) and its response to fertilizer tests and pilot amounts of pond stabilized wastewater from the Houghton Lake area community. Within 100 meters of the pond effluent outlet point (approx. 7.8 acres [3.2 ha] total area) phosphorus in the wastewater (100,000 GPD) had virtually disappeared and nitrogen was at or below background levels. Phosphorus adsorption by the peat and denitrification are credited with the removals. The peatland is now a full-scale component of the wastewater treatment process (1 MGD [3,786 m^3/da]). With time, the wastewater is expected to produce a more fertile wetland more accommodating to wildlife. Demgen, *et al.* (6) report on the interaction of secondary-treated chlorinated wastewater (design flow 1.6 MGD [6058 m^3/da]) from the Mt. View Sanitary District (California) with 8.8 newly created wetland acres (3.6 ha). In most six month periods, BOD_5 is reduced by 30 to 65 percent while suspended solids, mostly in the form of algae, are usually increased in the marsh effluent. The wetland supports at least 8 species of nesting birds and a large number of aquatic invertebrate species.

The following tentative trends are observed in the literature cited immediately above:

1. Seepage wetlands may act similarly to flood irrigation-forage grass systems in the virtual completeness of phosphorus removal effected by seepage through soils. In both systems, the vegetation is of secondary importance in phosphorus removal, while soil-water reaction during infiltration is primary.

2. Nitrogen removals by oxidation-denitrification may be excellent in wetland soils and very shallow seepage zones.

3. Lateral flow of secondary wastewater through wetlands may produce excellent net removal of phosphorus where effective contact of wastewater with peat occurs. Where peat or other reactive substrate is not significantly present, heavy rainfall or excessive wastewater flows would be a threat to retention of phosphorus, BOD and suspended solids in flow-through type wetlands due to washout of these substances in the runoff.

The Vermontville system was intended, in the conceptual stages, to provide phosphorus removal both by harvesting of terrestrial grasses and by soil-water contact as wastewater seeps downward from the irrigation fields. Up to four inches of water applied over several hours time once each week would flood the fields briefly until the water seeped away. The upper pond (Pond 1, Figure 1), has separate discharge lines into fields 1 and 2, and the lower pond (Pond 2) has separate discharge lines into fields 3 and 4. Pond-stabilized wastewater is released into each field by gravity flow through 10-in. (0.25 m) main and 8-in. (0.2m) manifold pipe having several ground level outlets in each field. Should the water level exceed 6 in. (15.2 cm) or so, water would overflow to the next field by means of a standpipe drain. All applied water would seep into the ground before leaving the treatment area.

The system is operating nearly in this manner today. There is a constant surface overflow from the final field, made up of ground-recycled wastewater which enters the final field at springs. This water is supplemented with direct surface overflow from field 3 during heavy or prolonged rainfall. Essentially, the system is a seepage wetland complex and very similar to a conventional flood irrigation facility. The vegetation and relatively small surface overflow from the final field have given us an established system in which to compare the treatment aspects of seepage versus lateral flow-through, the potential nutrient removal and wildlife values aspects for the strictly voluntary wastewater wetland, and the economics of the system compared to conventional alternatives.

PROCEDURES

The complete field and laboratory procedures are available from the authors. Approximately 25 million gallons (94,661 m^3) of wastewater were applied to the fields in June through October, 1978. Irrigation was done during 3 or 4 hours on each day of the 5-day week, except when heavy precipitation intervened. The Vermontville wastewater treatment personnel made weather observations and noted any field-to-field overflow on a daily basis. Williams & Works personnel made approximately biweekly water quality sampling visits and performed chemical and bacteriological analyses. Influent, pond effluent, wetland field surface waters, ground water and final surface overflow were tested. Late in the season, porous cup lysimeters were installed in fields 1 and 3 at depths of 1 ft to 3 ft (0.3m to 0.9m) to test the quality of shallow seepage waters. Field procedures related to the biomass and nutrient uptake studies are given in the Vegetation section.

WATER QUALITY

Wastewater Dilution Across The Site

The water quality results are summarized in Figure 2. Greater than two-fold dilution across the system is evident in the decreasing chloride concentration from 286 mg/l in the effluent to 124 mg/l in the ground water. Pond effluent is 25% diluted with respect to influent. Although a few inches of precipitation in excess of evaporation from the ponds occurred during the summer, the 25% dilution is more importantly due to excessive snow and ice meltwater added to the ponds in spring 1978. The 25% dilution between the pond effluent and the water standing in the wetlands is due principally to a large number of sampling dates coinciding with significant rainfall. Greater than 20 inches (50.8 cm) of rain fell in the 4½ months from June to mid-October, which is approximately 50% higher than the normal rate. The decrease in concentration between irrigation fields and ground water is due to mixing of wastewater with more dilute ambient ground water.

Phosphorus

Phosphorus in the wetland field waters is more concentrated than in the pond effluent. With allowance for dilution, orthophosphorus increases two-fold and total phosphorus increases by 50% in the wetland waters. Decomposition of detrital organic matter is a likely source of the additional phosphorus. Also, vegetation data show loss of phosphorus in the standing wetland crop over the irrigation season. Some amounts of the lost phosphorus is probably stored in plant roots and rhizomes, but some of the phosphorus might also have been released into the standing water. No testing of nutrient levels in submerged plant parts was done. Phosphorus is removed to the extent of around 97% between the wetland fields and the ground water, which is sampled from monitoring wells placed at depths ranging from roughly 10 ft to 25 ft (3.0 m to 7.6 m) below the wetland floors. Most removal of phosphorus occurs in the upper 3 ft (0.9 m) of soils judging from a small number of lysimeter samples which averaged 0.11 mg/l total P and 0.06 mg/l ortho-P, with ranges of 0-0.3 mg/l and 0-0.2 mg/l, respectively. The average removal of phosphorus effected in the upper 3 ft (0.9m) of soils are approximately 95%.

Nitrogen Forms

Levels of nitrate-nitrogen increase approximately 60% between the pond discharge and the wetland standing water, indicating that aerobic bacteria are at work in the wetland waters. On the other hand, the sediments are anaerobic as evidenced in the fetid odor which evolves when they are disturbed. Loss of some of the nitrate by denitrification is apparently occurring. Lysimeter samples show nitrate-nitrogen ranging from 0.0 to 0.9 mg/l, which suggests that denitrification of approximately 60% of the nitrate occurs in the shallow wetland soils. The ambient ground water contains higher levels of nitrate-nitrogen than does the seeping wastewater.

Levels of TKN and ammonia-nitrogen seem not to change much between the pond discharge and the wetland waters. But this constancy is likely only apparent, with organic nitrogen and ammonia probably being produce through anaerobic decomposition in the wetland sediments and being consumed in the aerobic wetland waters.

Surface Overflow

The overflow from final wetland field 4 contains a fairly constant amount of wastewater which has seeped from the higher elevation wetland flowed through the ground, and entered field 4 springs. This wastewate component is of high quality as is the ground water recovered from the monitoring wells. Pond effluent released directly into field 4, and overflow of wastewater from field 3 into field 4 at times of rainfall reduces the quality of water which overflows from field 4. The overflowing water at times contains phosphorus, BOD and suspended solids in slight excess of stringent effluent limits. The receiving stream is the Thornapple River, which is a first quality warm water stream, and which is impounded within several miles downstream to form a "lake" before it continues onward to Lake Michigan by way of the Grand River. The average final overflow quality is compared with the NPDES limits in Figure 2. The results support those obtained under somewhat different circumstances and reported in the literature which suggest that the flow-through process, absent filtration of wastewater through native soils, might not provide satisfactory removal of phosphorus.

VEGETATION STUDIES

Introduction

The objectives were to study the relationships between biomass accumulation and nutrient uptake and to determine the appropriate above-groun plant harvest so as to effect the maximum removal of phosphate. Severa previous studies on natural wetland macrophytic species, including cattail (*Typha latifolia* L.,), demonstrated pronounced seasonal periodicity in tissue nutrient uptake. Rapid uptake of nitrogen and phosphorus occurred during the spring-early summer with the continuous translocation of these nutrients from the older above-ground tissues to newer growth. A decline in total plant tissue nutrient levels took place ove the remaining growing season (8, 9,10,11,12,13). Recently, these observations were confirmed for macrophytes in artificial wetland systems. Harvesting above-ground plant parts at the time of highest concentrations of nutrients in young tissue has been demonstrated as a reasonabl technique for removal of a portion of applied nutrients from the wetland system (11).

Materials and Methods

Floristic description and mapping indicated eight different community types ranging from seasonally wet/dry grassland on the more elevated areas of the fields through a series of cattail community types with increasing water depths to duckweed ponds varying in water depth from ten inches (0.25 m) to 1.5 ft (0.46 m) in depressions. In order to determine the standing crop and tissue nutrient levels for each of these communities, above-ground plant parts were harvested at monthly intervals between late-June and November, 1978.

Three one-quarter m^2 or 1 m^2 quadrats were harvested from each different community type occurring within the four fields and bordering Pond 2. The emergent shoots from each quadrat were cut at the soil level, bagged, and dried at 60° C for 72 hours. After an initial 5-hour drying time all collections were weighed and then three shoots from each quadrat were removed, weighed, macerated, and frozen for nitrogen and phosphorus determinations.

Results

Eight plant communities are described in Table 1. The standing crops are summarized for each of the wetland fields and for Pond 2 in Table 2. Standing crops for the eight communities varied from a minimum of 7,348 lb/ac (8,291 kg/ha) in field 3 on October 10, 1978 to 23,692 lb/ac (26,000 kg/ha) in Pond 2 on July 19, 1978. Maximum standing crops for the communities varied from a low of 6,500 lb/ac (7,298 kg/ha) for duckweed (*Lemma minor* L.) to a high of 19,773 lb/ac (22,155 kg/ha) for robust cattail (*Typha latifolia* L.) (Table 3).

Maximum nutrient levels among wetland communities occurred at the time of maximum standing crop. Community types 1, 2, 4, 5, 6 and 8 (Table 1) attained these highest nutrient levels July 3, 1978, while the highest levels for community type 7 occurred September 10, 1978 (Tables 4 and 5). Nutrient concentrations in above-ground tissues of cattail were highest in leaves and fruits and lowest in the older stem tissues (Table 6). This distribution pattern of highest concentration in young (maturing) tissue, decreasing with increasing tissue age, persisted throughout the growing season.

The projected single-harvest nutrient yields were maximum in fields 1-4 on July 3, 1978, and in Pond 2 on September 10, 1978 (Figure 3). Observations over the summer on the lack of vegetative recovery (new shoots or re-growth) of prior-harvested above-ground plant parts indicate that only a single harvest is possible.

WILDLIFE VALUES

The Vermontville volunteer wetland system created marshland habitat suitable for waterfowl production otherwise not present in the immediate area. Many other types of birds also nested in the marshes, including red-wing blackbirds, American coot, and American goldfinch. Other waterfowl (blue-winged teal and mallard), shorebirds (gallinule, killdeer, lesser yellow-legs, and sandpiper) and swallows used the wetland-pond system for feeding and/or resting during their migration. Seasonal use of the system for red-wing blackbirds and black ducks, and observations for other birds are depicted in Figure 4. Great blue heron, green heron, ring-neck pheasant, and American bittern were also seen frequenting the wetlands.

These volunteer wetlands were also important habitat for numerous amphibians and reptiles. The occurrences of these species are noted in Table 7. Muskrats inhabited the wetlands, while raccoon, white-tail deer, and woodchuck were seen feeding in the wetlands.

OPERATION AND MAINTENANCE COST COMPARISON

An important aspect of the Vermontville system is that no cutting or soil tilling seems to be needed after six seasons of use of the wetland fields. Natural seepage wetlands in glacial soils seem to function for hundreds and thousands of years without plugging and overflowing, and perhaps this kind of longevity should be expected of manmade wetland seepage systems also, provided that they receive only insignificant quantities of inorganic detritus. Perhaps the aerobic and anaerobic processes which operate in such wetlands keep the soils open for internal drainage.

Table 1 compares treatment O&M costs for five Michigan communities of population 750 to 975, including Vermontville. To keep the comparison relevant to seepage wetland costs, only post-secondary and phosphorus removal costs are considered. Some items are not included in the presentation of costs. Water quality monitoring and testing and some clerical costs are quite uniform, amounting to perhaps $1500 per year for all of the communities. These costs are not included in the comparison, nor is overhead on labor. Four of the five communities use stabilization ponds followed by some kind of phosphorus removal scheme, either wetlands or ridge-and-furrow irrigation or spray irrigation. The fifth community has a conventional activated sludge plant. There is a second community in addition to Vermontville with a fortuitous wetland system, for which labor involved with manual valve control and routine inspection account for nearly the entire cost of $921 on a 0.1 MGD (378.6 m/da) basis. Vermontville's costs, $2146 on the same basis, are mostly labor and equipment required to mow the exceptionally large irrigation field berms (see Figure 1). About 100 hours time is involved with manual valve control also. The ridge-and-furrow irrigation system costs are labor intensive, involving maintenance of the ridge-and-furrow field surface and an overflow structure. The spray irrigation system has repair and replacement costs above those of the other land disposal systems. The activated sludge plant has significant labor and chemical (ferric chloride) costs.

The comparison of O&M costs can be summarized in two points:

1. The O&M for seepage wetlands can be very low.
2. The O&M is about the same for the more expensive wetland scheme as it is for the less expensive conventional irrigation scheme.

DELIBERATE CONSTRUCTION OF SEEPAGE WETLANDS

In the design of nearly maintenance free seepage wetlands, the kind of native soil would be important. The idea is to have slow seepage but at the same time adequate seepage to prevent surface runoff. A natural setting to avoid is clay or heavy clay loam. Depending on actual soil conditions, an overflowing pond may result instead of a seepage wetland. At the other end of the soil texture spectrum is clean uniform sand. The water intake of uniform sand would have to be restricted with a soil sealant or a clay layer, hence unwelcome capital and O&M costs might not be avoidable. The kinds of soils that should serve well are somewhat silty in composition. A number of unified soil classes have typical hydraulic conductivities in the range 10^{-3} to 10^{-5} cm/sec. The most useful range for seepage wetlands is 10^{-4} to 10^{-5} cm/sec.

The useful soil classes are depicted in Table 2. If natural soils are in the 10^{-3} to 10^{-5} range, care can be taken in grading the wetland site either to compact the soil deliberately or avoid compacting to get the desired intake condition. Natural soils with more restrictive permeability (10^{-4} - 10^{-6} cm/sec) would be more difficult to work, but would be suitable in their natural condition if not too tight and if there is adequate depth to the water table to permit sufficient contact between the seeping wastewater and the soils.

A rendering of a deliberately constructed seepage wetland is shown in Figure 5. Assuming that construction is done on a tract having soils in the 10^{-3} - 10^{-5} cm/sec permeability range, grading with heavy equipment might be done over the area to be submerged in order to get adequate soil tightness. The compacted zone would be a foot or so thick. In order to be sure of contained flooding in the event of overflow of the compacted zone, an uncompacted narrow strip could be included as a perimeter to absorb any overflow. Wetland vegetation would begin to establish during the first season of irrigation and might be well established by the end of the second season or into the third.

In the spectrum of land application methods through which adequate tertiary treatment is attainable, seepage wetlands are the wet "end member" while the conventional surface irrigation configurations and seepage ponds occupy the continuum between wet and nearly dry, depending upon actual conditions.

CAPITAL COST COMPARISON

Seepage wetland costs are compared with spray irrigation costs in Figure 6. Spray irrigation costs were worked out two years ago in great detail for ten small Michigan communities with flows up to about 0.24 MGD (7). In every case, spray irrigation sites are within three pipeline miles of secondary treatment systems. Costs including land costs were updated to 1979 times. Additional assumptions not stated in the figure are spray irrigation equipment costs between $3,400 and $3,500 per acre and wetland area grading costs of $4,000 per acre.

The spray irrigation cost curve shows that a 0.28 MGD (1,060 m^3/da) system would cost around $1 million and a 0.5 MGD (1,893 m^3/da) system would cost around $1.6 million. Much of the high cost of spray irrigation systems is involved with the land required for up to 900 ft (274m) of isolation between the spray perimeter and residential properties. Below 0.1 MGD (379 m^3/da) seepage wetland cost savings are 26% or greater. The savings are relatively less as the size of the system increases. The capital cost advantages for seepage wetlands would be greater in areas of even topography where minimal grading would be required. Land costs in excess of $1,153 per acre ($2,848/ha) would also make the seepage wetland systems relatively more advantageous.

DISCUSSION AND CONCLUSIONS

The volunteer wetland vegetation-organic mat complex at Vermontville actually adds phosphorus to wastewater during the late spring and summer irrigation season. Consequently, the wetland waters overflowing at the final discharge contain phosphorus in slight excess of permitted levels, absent a significant amount of diluting wastewater which has previously been filtered through the inorganic soils. Phosphorus removal adequate to satisfy strict effluent requirements is accomplished only by seepage from the wetlands through the inorganic soil substrate.

Seepage wetlands have capital cost advantages for tertiary wastewater treatment, compared to spray irrigation. This is especially true for wastewater flows of 0.1 MGD (379 m^3/da) or less, and for higher flows up to at least 0.5 MGD (1,893 m^3/da) on even terrain requiring only minor earth moving. Land required for isolation of spray irrigation sites and spray irrigation equipment, and the possibility of significant land grading requirements for seepage wetland systems, are the most significant factors in the capital cost differences between the two systems. In the higher flow ranges, spray irrigation costs might be partly offset by agricultural production, but for smaller flows smaller tracts of land are often not economical to farm.

No field maintenance has been required at Vermontville. There are no bare soil (tilled) areas to be plugged through siltation caused by rain splash, spray irrigation, or flood-suspension of inorganic soils. The Vermontville wetlands have shown buildup of three or four inches (0.1 m) of organic residues largely in the form of cattail straw after six irrigation seasons. Over the 20-year design period the net accumulation would likely be less than 1 ft (0.3 m) due to progressive compaction and further decomposition of older plant residues. Tree control is not needed at Vermontville, although one of the fields may soon be overgrown with willow whips. On fields which might depend upon a thin compacted soil zone or other seepage restricting improvement, tree control might be needed to maintain the integrity of the conditioned soil zone.

The uptake of phosphorus by the prevailing cattail standing crop is approximately 20% of the phosphorus released into the wetlands. Cattail harvesting would therefore be a means of reducing effluent phosphorus. But harvesting is not needed for phosphorus removal in seepage wetland settings where subsurface soil types and volumes are adequate to effect phosphorus removal before effluent ground water reaches receiving streams. Removal of the cattail at its peak standing crop biomass and nutrient stage (late June, early July) would not of itself result in a satisfactory surface discharge at Vermontville, although an annual harvest program implemented very early in the history of such a facility should result in less decomposing plant material and perhaps lower wetland wastewater phosphorus levels than are present at Vermontville.

Casual observation in 1978 reveals the wastewater-grown wetlands have significantly added to the acreage of suitable, adequately isolated habitat for waterfowl and other wildlife in the Vermontville area. Natural, interrupted zones of attached aquatic plant life fringe the nearby Thornapple River but these are narrow, small and easily accessible to fisherman and other recreationists. The wastewater wetlands are not exposed to casual trespass, being part of a restricted wastewater treatment site. The authors intend in 1979 to document more thoroughly wildlife species numbers and benefits afforded them in the wastewater wetlands, and to evaluate the volunteer wetlands as sanctuary for several sensitive plant species.

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Any opinions, findings and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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TABLE 1

Community Types, Vermontville Volunteer Wetlands[1]

Community Number and Description with Conspicuous Dominant Plant Species	Presence in Field or Pond 2 1	 2	 3	 4	 P2
1. Willow *(Salix spp.)* Shrub with Cattail *(Typha angustifolia L.)*	(X)[2]	(X)	(X)	(X)	
2. Narrow-leaved Cattail *(Typha angustifolia L.)*	X	X	(X)	(X)	
3. Grassland Vegetation with Goldenrod *(Solidago spp.)*	(X)	(X)	X	(X)	
4. Narrow-leaved Cattail *(Typha angustifolia L.)* with Grassland Vegetation	(X)	(X)			
5. Narrow-leaved Cattail *(Typha angustifolia L.)* with Duckweed *(Lemna minor L.)*	X	X	X	X	
6. Duckweed *(Lemna minor L.)*	(X)	(X)			
7. Robust Cattail *(Typha latifolia L.)*	(X)	(X)			X
8. Narrow-leaved Cattail *(Typha angustifolia L.)* with Curly-Dock *(Rumex crispus L.)*			X		

[1] Detailed phytosociological descriptions are available for each community type.

[2] (X)-less than 0.2 acres present in field.

TABLE 2

Standing Crop (lbs/acre), Vermontville Volunteer Wetlands, Summer-Fall 1978[1]

Field or Pond	Acreage of Marsh	-lbs/acre- 7/3	 7/19	 8/14	 9/10	 10/10
1	3.276	14,998	14,384	10,725	10,456	8,982
2	2.836	15,371	14,703	11,591	10,881	8,729
3	3.556	14,103	11,208	10,040	11,066	7,385
4	1.849	10,812	8,720	10,887	11,373	10,892
P2	1.232[2]	20,819	23,692	22,800	21,204	17,654

[1] Dry-weight in lbs/acre above-ground plant parts only.

[2] Acreage in vascular plant vegetation only.

TABLE 3

MAXIMUM PRODUCTIVITY STANDING CROP (LB/AC)

COMMUNITY TYPE		PRODUCTIVITY
ROBUST CAT·TAIL	(7)	19,773
NARROW·LEAVED CAT·TAIL (C·T)	(2)	15,518
NARROW·LEAVED C·T W/DUCKWEED	(5)	13,067
NARROW·LEAVED C·T W/GRASSLAND	(4)	10,719
NARROW·LEAVED C·T W/CURLY·DOCK	(8)	9,315
WILLOW SHRUB W/C·T	(1)	8,307
GRASSLAND AND GOLDENROD	(3)	6,724
DUCKWEED	(6)	6,500

FIELD	PRODUCTIVITY
(POND 2)	23,692
2	15,371
1	14,998
3	14,103
4	11,373

TABLE 4

Total Phosphorus in lbs/acre
Vermontville 1978

Field or Pond	Sampling Date 6/28-7/3	9/10	10/10
1	6.7327	2.3803 (-64.6)*	0.7643 (-67.9)
2	7.1038	3.1643 (-55.4)	0.8350 (-73.6)
3	6.2937	4.6258 (-26.5)	3.1346 (-32.2)
4	3.6499	2.0802 (-43.0)	2.0471 (-1.6)
P2	10.7326	16.5887 (+54.6)	1.3052 (-92.1)

* % change from earlier date.

$\overline{X}$ change (excluding P2 values) = -45.6%;
6/28-7/3 to 9/10 = -47.4%
9/10 to 10/10 = -43.8%.

TABLE 5

Total Kjeldahl Nitrogen in lbs/acre
Vermontville 1978

Field or Pond	Sampling Date 6/28-7/3	9/10	10/10
1	38.1957	25.6865 (-32.7)*	22.3948 (-12.8)
2	39.3787	22.4394 (-43.0)	9.6643 (-56.9)
3	25.0797	25.9417 (+ 3.4)	11.1714 (-56.9)
4	23.8400	20.3134 (-14.8)	13.6641 (-32.7)
P2	24.7900	27.0376 (+ 9.1)	11.0524 (-59.1)

* % change from earlier date.

$\overline{X}$ change = -29.64%
6/28-7/3 to 9/10 = -15.6%
9/10 to 10/10 = -43.7%

TABLE 6

Nutrient Distribution (mg/kg) in Above-Ground Tissues of Cattail *(Typha spp.)*

Plant No.	Sampling Date	Tissue	Phosphorus	Nitrogen
1	7-03-78	Leaves	58	1848
		Stems	18	526
2	7-14-78	Leaves	38	1482
		Stems	28	204
		Fruits	55	678
3	8-21-78	Leaves	83	1902
		Stems	40	273
		Fruits	140	1140
4	8-21-78	Leaves	150	2040
		Stems	43	383
		Fruits	206	1386
5	9-10-78	Leaves	98	400
		Stems	18	280
6	9-10-78	Leaves	154	703
		Stems	18	208
7	9-16-78	Leaves	149	673
		Stems	50	119
		New Shoots	121	389

TABLE 7

Amphibians and Reptiles, Vermontville Volunteer Wetlands

	Presence in Field or Pond					
Species	1	2	3	4	P1	P2
Snapping Turtle, *Chelydra serpentina*		X			X	X
Eastern Painted Turtle, *Chrysemys picta picta*		X			X	X
Eastern Garter Snake, *Thamnophis sirtalis sirtalis*			X	X		
Eastern Milk Snake, *Lampropeltis triangulum triangulum*			X	X		
American Toad, *Bufo americanus*	X	X	X	X		X
Bullfrog, *Rana catesbeiana*		X				X
Green Frog, *Rana clamitans melanota*	X	X	X	X		X
Northern Leopard Frog, *Rana pipiens*	X	X	X	X		X

TABLE 8

*O&M/YR

POST·SECONDARY AND PHOSPHORUS REMOVAL, MICHIGAN COMMUNITIES

SYSTEM	POP.	FLOWS (MGD)	$, 1 MGD BASIS
PONDS, WETLAND	750	0.07	$921
PONDS, WETLAND	975	0.067	$2,146
PONDS, R·F IRRIG	925	0.094	$1,915
PONDS, SPRAY	975	0.11	$2,867
ACTIV. SLUDGE	750	0.107	$3,423

* DIRECT LABOR AND OTHER FIELD COSTS ONLY

TABLE 9

UNIFIED SOIL CLASSES
WITH HYDRAULIC CONDUCTIVITY

10^{-3} to 10^{-6} cm/sec

CLASS	TYPICAL NAMES	WORKABILITY
GM	SILTY GRAVELS & GRAVEL-SAND-SILT	**GOOD**
SM	SILTY SANDS & SAND SILT MIXTURES	**FAIR**
SC	INORGANIC SILTS VERY FINE SANDS SILTY OR CLAYEY FINE SANDS CLAYEY SILTS (LOW PLASTICITY)	**FAIR**

10^{-4} to 10^{-6} cm/sec

OL	ORGANIC SILTS ORGANIC SILTY CLAYS (LOW PLASTICITY)	**POOR**
MH	INORGANIC SILTS MICACEOUS OR DIATOMACEOUS-FINE SANDY OR SILTY SOILS ELASTIC SILTS	**POOR**

MOST DESIRABLE RANGE 10^{-4}-10^{-5} cm/sec

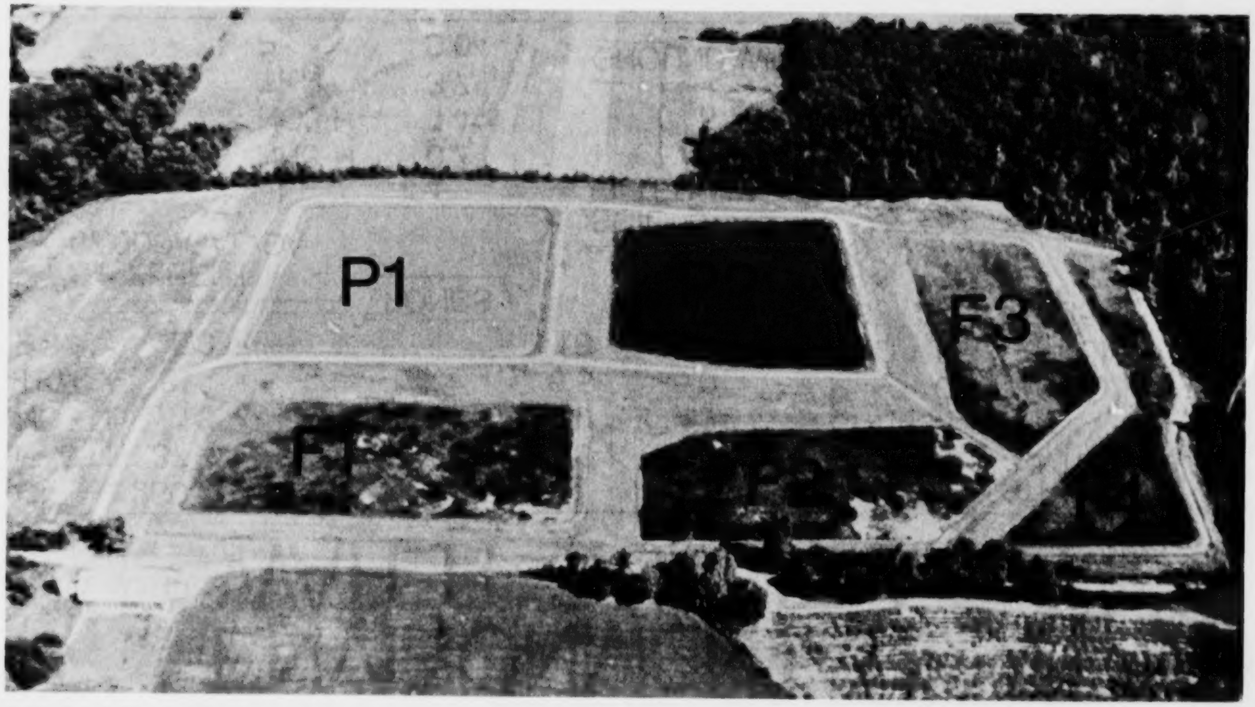


Figure 1. Wastewater Stabilization Ponds (P) and Irrigation Fields (F).

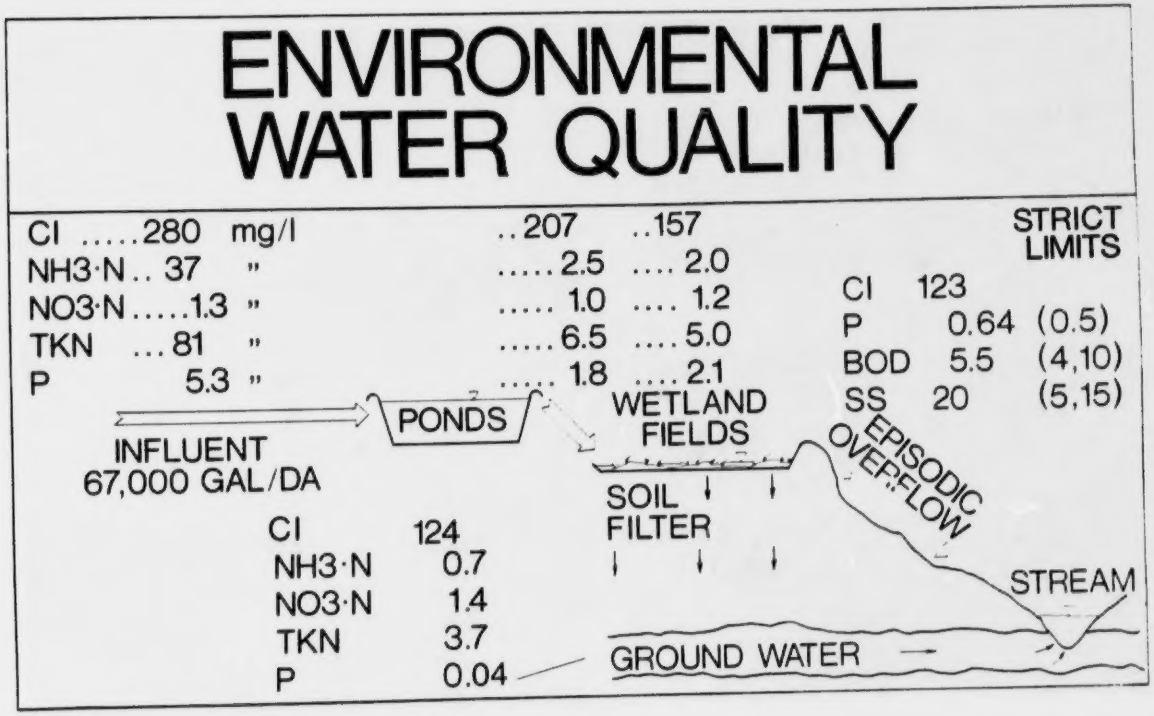


Figure 2. Environmental Water Quality.

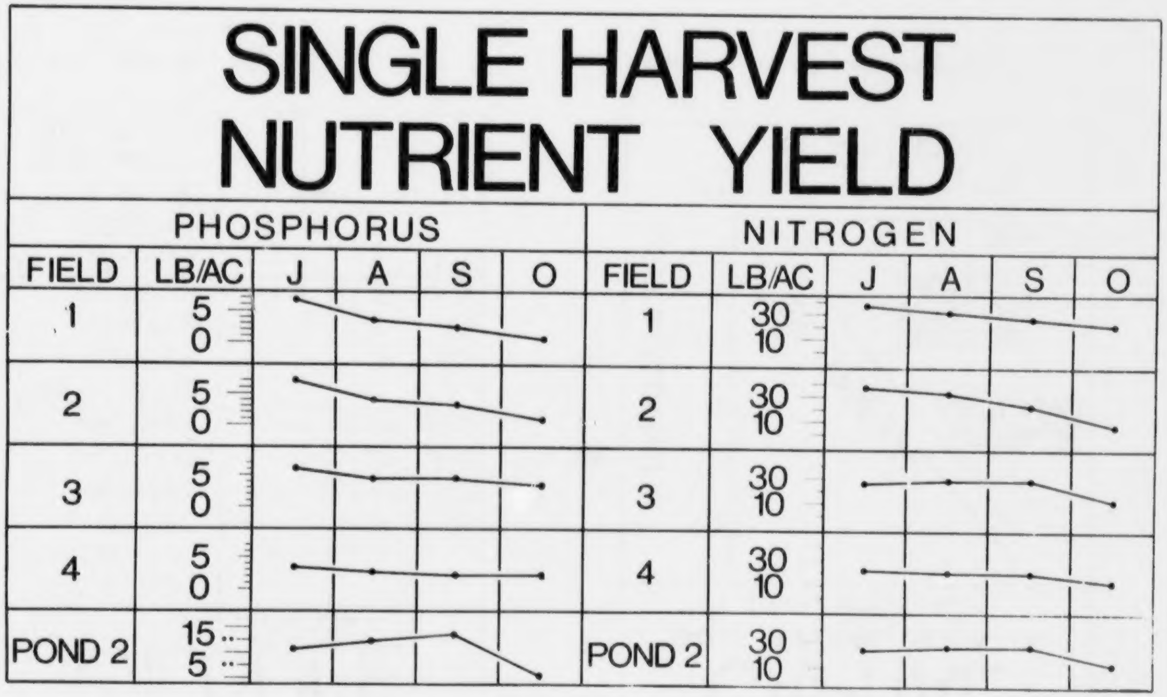


Figure 3. Single-Harvest Nutrient Yield.

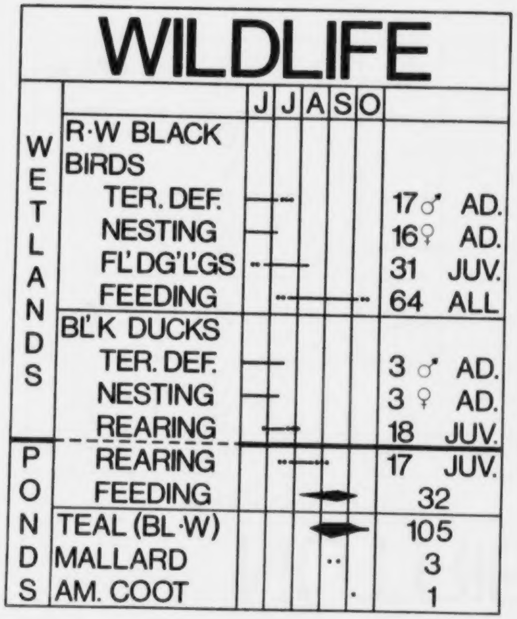


Figure 4. Marsh Bird Values.

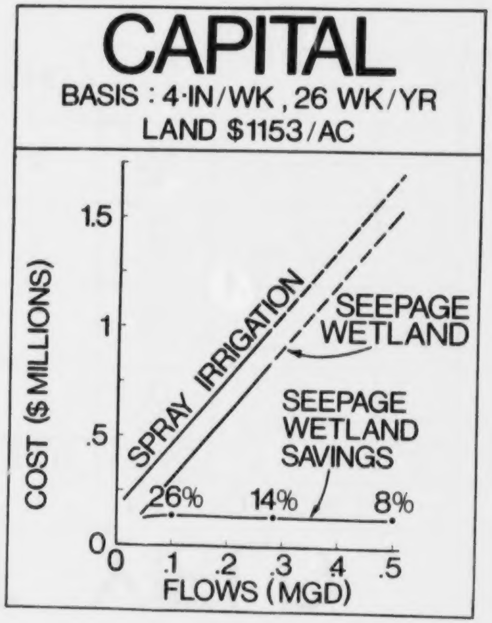


Figure 5. Capital Cost Comparison.

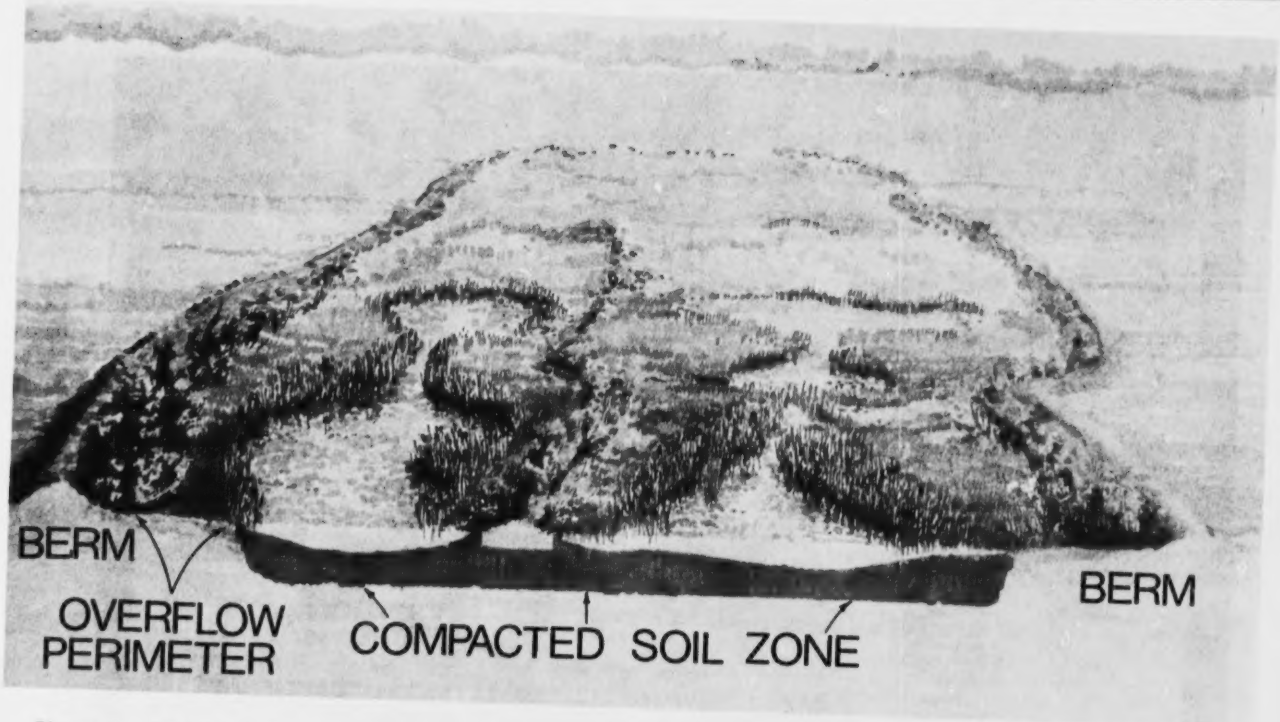
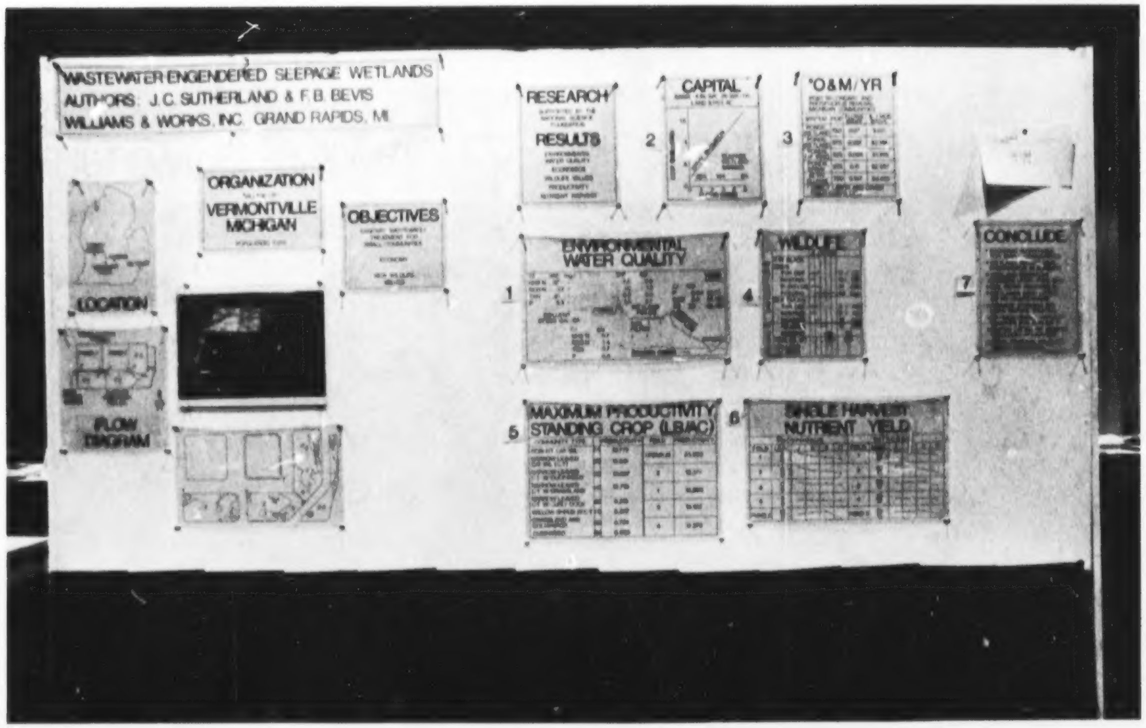


Figure 6. Rendering of a Man-made Seepage Wetland.


WASTEWATER ENGENDERED SEEPAGE WETLANDS
AUTHORS: J.C. SUTHERLAND & F.B. BEVIS
WILLIAMS & WORKS, INC. GRAND RAPIDS, MI
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